Environmental and Institutional Background for CALFED's Environmental Water Account

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October 2001

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Introduction

This report provides background information for reviewing 2000–2001actions taken to implement the first year of CALFED's Bay–Delta Program's Environmental Water Account (EWA). The EWA, an integral component of CALFED's Water Management Program, uses water acquired through purchases and other means to help protect fish resources of the Central Valley and San Francisco estuary, while helping provide assurances that there will be no reductions in the amount of water supplied to urban, industrial and agricultural water users.

A separate report being prepared by the California Department of Fish and Game (DFG), the National Marine Fisheries Service (NMFS), and the U.S. Fish and Wildlife Service (USFWS) (together, the Management Agencies) will describe in detail the rationale and basis for particular actions taken and an analysis of these actions.

This report provides background information intended to help understand and interpret information about specific EWA actions. We anticipate that in future years the general information presented here will remain much the same, while the specifics reported by the Management Agencies will vary depending on the actions taken.

Although this report has been reviewed by agency and stakeholder staff, we assume full responsibility for its contents.

The CALFED Bay–Delta Program

CALFED arose out of efforts in the early 1990s to resolve conflicts over water allocation in the Central Valley and the San Francisco Estuary. Increased population growth was taxing water supplies and several species of fish declined in abundance, with two species, winter chinook and delta smelt, listed pursuant to the state and federal endangered species acts. In 1994 state and federal agencies signed the Framework agreement and agencies and stakeholders signed the "Delta Accord." These agreements called for interim environmental protection measures and provided time for a new entity, CALFED, to develop long-term measures and actions to provide for environmental restoration and improved water quality and reliability of water exported from the Sacramento–San Joaquin Delta.

In 2000 CALFED completed programmatic environmental documentation for its proposed program, including a Record of Decision. Water management was a key CALFED program element and the EWA was a major component of the program.

Water Project Operations

Although we describe water projects and their operations in more detail later in the report, mention is made here to help set the stage for understanding the EWA. The State Water Project (SWP) and the federal Central Valley Project (CVP) capture and store stream runoff in a series of reservoirs in the Sacramento and San Joaquin basins. The water projects release stored water to meet instream flow requirements, flood protection, recreation, and power generation, and to supply water to contractors. Much of the water supply is released from upstream reservoirs to flow down the rivers to the Sacramento–San Joaquin Delta, then diverted from the southern Delta by separate large pumping plants. The amount of water exported from the Delta varies with natural inflows, releases of stored water, pumping capacity, environmental and other regulations, and demand by contractors.

Water project exports from the Delta change internal net flow patterns and kill fish at the intakes, including entrainment through fish screens, impingement, losses to predators, and handling of captured fish in the salvage process. Indirect effects include mortality due to predation in waterways leading to the export facilities, and may include effects of altered net flow patterns in the Delta. Implementation of the EWA to protect fish can involve temporary reductions in pumping.

Environmental Water Account

The EWA itself is explained in much greater detail in a separate report to the review panel by the EWA environmental team. This brief explanation is included to help this report stand alone.

The underlying concept of the EWA involves acquiring water through direct purchases, temporary relaxation of environmental standards, and other means, and then using the acquired water ("assets") to protect fish. In a simple example, EWA might purchase 50,000 acre-feet (af) of water from a willing seller north of the Delta and store the water in a reservoir south of the Delta. Management agencies asking for a temporary reduction in Delta pumping would use their EWA assets to reimburse the water costs of this curtailment. In another example, during a period when fish concerns were minimal, the management agencies might approve a temporary reduction in an environmental standard (for example, the allowable ratio of water project exports to inflow to the Delta). With the relaxed standard, the water projects would be permitted to pump more water and this water would go into the EWA account for later use.

EWA actions are categorized under three "tiers":

- **Tier 1—**No use of EWA water: existing regulatory and other mechanisms provide adequate resource protection. The "baseline" condition.
- **Tier 2—**Regular EWA assets (water) are used to protect fish as the need arises.

- **Tier 3—**Extraordinary circumstances dictate that EWA managers acquire and use additional water. Acquisition of Tier 3 assets may require paying a premium price. There was no Tier 3 water available in 2000–2001.

EWA implementation is funded from a special CALFED account. This past year, the account contained about 60 million dollars to purchase water, pay for transportation and power costs, fund environmental documentation, and support other related activities.

A basic tenet of the EWA is that its actions may not reduce deliveries of water to water project contractors. Through purchases and other means, the EWA acquires a quantity of water going into the October through June fish protection season. (Additional water may be acquired during the season.) Agency biologists use fish abundance, flow, and fish salvage at the water project intakes to develop recommendations for fish protection. These recommendations result in incremental withdrawals from the EWA account. When the account reaches zero, water project operators are no longer obligated to implement recommendations that result in decreased water supplies.

The EWA targets several sensitive fish species that spend at least some time in the Delta. These species include chinook salmon (including all four races, defined by the season at adults migrate into the rivers to spawn), steelhead, delta smelt, splittail and green sturgeon. Four of these fish (winter and spring chinook, delta smelt, and splittail) are listed under either or both of the federal or state endangered species acts. In a typical EWA action, agency biologists would use catch data to determine that juvenile salmon are about to become vulnerable to water project pumping and would recommend that pumping be curtailed. The water project operators would estimate the water costs of reduced pumping, and if EWA water were available, would implement the recommendation.

EWA in the Context of Other Restoration and Recovery Measures

Although the EWA is a key component of CALFED's water management plan, it is but one element of complex array of actions, regulations and programs being undertaken to restore aquatic and terrestrial ecosystems of the estuary and Central Valley. Some of these are described in more detail later but deserve mention at this time. They are not listed in any particular order of importance.

- **Water Rights Decision 1622 and the 1995 Water Quality Control Plan.** This decision and plan were issued by the California State Water Resources Control Board to protect and balance water needs for all Bay–Delta recognized beneficial uses. This plan includes the "X2" standard, an estuarine salinity standard in effect during spring, and a maximum export:inflow ratio that varies throughout the year. The standards are part of the "baseline" condition in EWA's Tier 1.

- **CALFED's Ecosystem Restoration Program.** This program includes a large number of actions and studies using an adaptive management process to restore significant ecological components of the Bay–Delta and its watershed. Actions can range from streambed rehabilitation to increasing shallow water and wetland habitat in the estuary.

- **CALFED's Environmental Water Program.** Part of the Ecosystem Restoration Program, the Environmental Water Program (EWP) will also be purchasing water from willing sellers for environmental purposes. This program is just starting and at the time this report was released CALFED had not made any EWP purchases.

- **The Central Valley Project Improvement Act.** In 1992 Congress passed legislation that made fish and wildlife protection an authorized purpose of the CVP. Included in the Central Valley Improvement Act (CVPIA) were several features important to ecological restoration. Three are most relevant to the EWA:

  The Anadromous Fish Restoration Program. The goal of this program is to double the natural production of five species of anadromous fish, including chinook salmon, steelhead and green sturgeon.

  Anadromous Fish Screen Program. This program provides funds for screening unscreened or poorly screened diversions that appear to be adversely affecting the targeted anadromous fish species.

  Dedicated CVP yield to the environment. The CVPIA provides up to 800,000 acre-feet of water for environmental protection (600,000 af in a dry year)—the so-called "b2" water (from section 3406(b)(2) of the CVPIA). Up to 450,000 acre feet of this allocation can be used in the Delta. In some instances, such as water project pumping curtailments called for in the Vernalis Adaptive Management Plan, (b)(2) water is used in conjunction with the EWA for environmental protection.

- **Vernalis Adaptive Management Plan.** The Vernalis Adaptive Management Plan (VAMP) is a 12-year program undertaken to improve understanding of effects of flow and exports on survival of emigrating San Joaquin chinook salmon smolts. During this study the effects of various combinations of San Joaquin River flow and water project pumping on survival of marked hatchery fish will be evaluated. In addition, the effects of a fish mitigation barrier will be tested.

- **Fish Mitigation Agreements.** Both the Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (USBR) have agreements with the DFG to mitigate the effects of direct losses of salmon, steelhead, and striped bass at the water project intakes. Funding through these programs has resulted in, among other things, habitat improvement, improved enforcement of fish regulations and screening of unscreened or poorly screened water diversions.

- **Biological Opinions.** Listing fish under the endangered species acts has resulted in many actions designed for environmental protection, particularly aimed at fish populations. The opinions have resulted in water project operations that help avoid jeopardizing the continued existence of these fish. The modifications to water project operations are part of the baseline program above which the EWA and other enhancement or restoration programs operate.

Environmental Setting

The EWA operates in the San Francisco Estuary (including the Sacramento–San Joaquin Delta) and its watershed. Here we describe some of the key estuarine and watershed features and then the SWP and CVP.

The Watershed

The Sacramento and San Joaquin rivers, and numerous major and minor tributaries drain the Sierra Nevada and coast range in the Central Valley catchment (Figure 1), comprising about 40% of the area of California. Major tributaries and streams, all with one or more dams, are: Feather River, American River, Mokelumne River, Stanislaus River, Tuolumne River, and the Merced River. Several smaller streams (Battle, Butte, Deer and Mill creeks, and the Bear, Yuba, and Cosumnes rivers) are ecologically important because of their fish runs.

Hydrology

California's Mediterranean climate has distinct wet and dry seasons, with about 80% of precipitation concentrated in November through March, and very little rain from June through September. This large seasonal variability, coupled with changing ocean conditions and water management, results in significant variation in the streamflows entering the Delta from the watershed (Figure 2). Water management attempts to minimize intra- and interannual variation to provide more constant water supplies, and these management practices have resulted in changes in the seasonal runoff pattern (Figure 3). Flow is now greater in streams entering the estuary during the summer and fall, and lower in winter, than historically. Summer and fall flows, mainly from reservoir releases, are elevated to meet urban and agricultural demands during the dry season. In recent years, streamflows and Delta inflow have also been modified to provide environmental benefits. During water years 1956 through 2000, the annual average total amount of water reaching the Delta has been about 25 million acre-feet (maf) or 31 cubic kilometers (km^3).

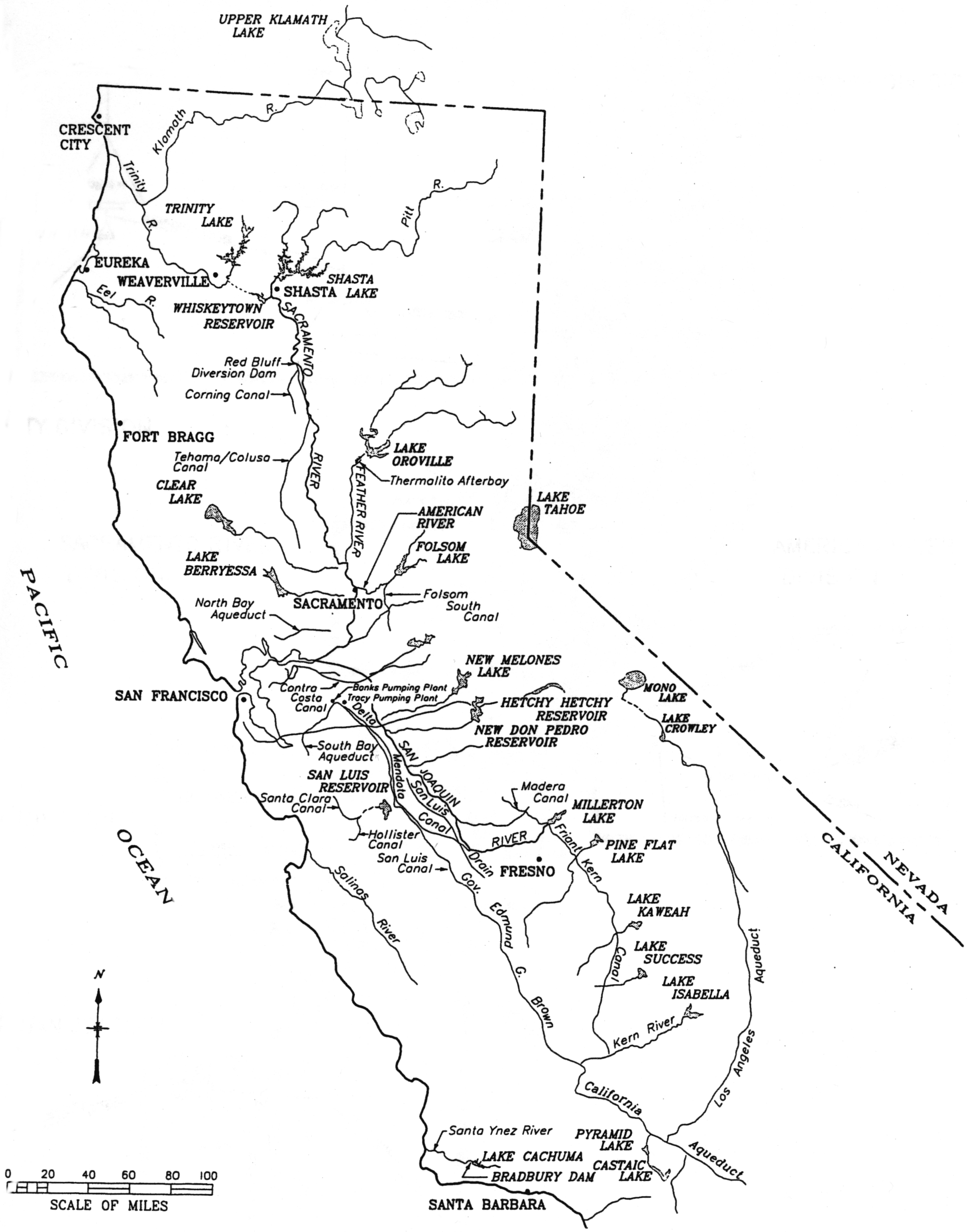


Figure 1 Major features of the Central Valley Project and State Water Project

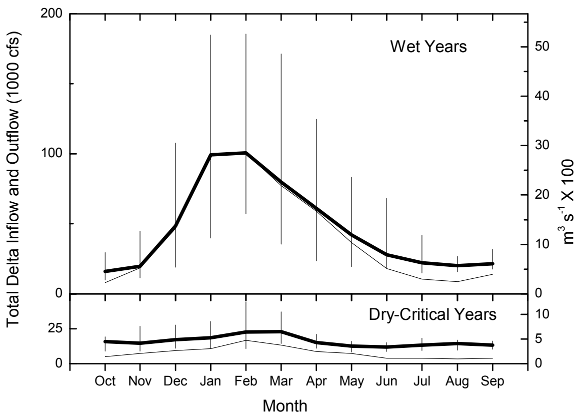


Figure 2 Seasonal patterns of flow into the Sacramento–San Joaquin Delta and outflow from the Delta. Source: DAYFLOW program (DWR) for water years 1956–2000. Inflow (heavy lines): medians with 10th and 90th percentiles for years designated as wet (above, 20 years) or dry or critically dry (below, 15 years). Outflow (thin lines): medians.

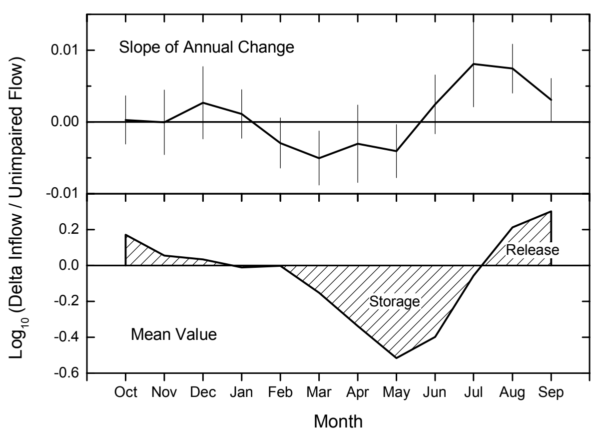


Figure 3 Log of the ratio of flow into the Delta to unimpaired flow for the same month. Top, slope of the log ratio vs. year with 95% confidence limits. A negative slope means that a progressively smaller proportion of the precipitation in the basin reaches the delta in the same month, that is, storage is increasing. Bottom, mean log ratio, where a positive value indicates more water is entering the delta than is available from precipitation, implying release from storage (natural or man-made). Source: DWR DAYFLOW and records.

The SWP and CVP divert water from the south Delta—the CVP since the early 1950s and the SWP from the late 1960s. The amount diverted is controlled by water availability, requests by water contractors, and environmental requirements. The State Water Resources Control Board (SWRCB), through its water rights and water quality authorities, defines environmental conditions needed to protect beneficial uses—conditions which affect reservoir releases and pumping. For example, SWRCB Decision 1622 imposes a limit of 35% and 65%, depending on the time of the year, on the ratio of exports to total inflow to the Delta, termed the export:inflow ratio. Figure 4 illustrates the total annual amount diverted from 1955 through 2000. Note that there is considerable interannual variation around the average annual export quantity of about 4 maf, with a range of 1.3 to 6.3 maf, but since the 1977 drought exports have consistently been above 3 maf. Figure 5 illustrates diversion patterns for two recent years: 1998 (a wet year) and 1991 (a critically dry year).

Key among the standards established by the SWRCB for the estuary is the "X2 standard." X2 is the distance up the axis of the estuary to where the near-bottom salinity is 2 practical salinity units. During February to June, X2 is regulated through manipulation of freshwater flow and pumping. The standard is scaled to the availability of freshwater. The basis for this standard is that abundance or survival of several species of fish and invertebrates varies positively with freshwater flow, or negatively with X2. Thus, this standard is intended to provide support for these populations a the ecosystem level rather than species by species.

Hydrology is calculated on the basis of water years, which begin on 1 October to encompass the entire wet season in most years. Water years are classified on the basis of total precipitation in the basin as wet, above normal, below normal, dry, or critically dry. In the illustration in Figure 5, 1998 was classified as wet and 1991 as critically dry.

A DWR spreadsheet program, DAYFLOW, takes inflow, pumping, and internal Delta precipitation and consumption to calculate the estimated Delta outflow. Figure 6 illustrates the average monthly Delta outflow from 1955 through September 2000. Outflow tracks inflow fairly closely; export flow does not change much from year to year and is uncorrelated with inflow on an interannual time scale. On a shorter time scale, water project operators manipulate inflow to match export flow and outflow requirements.

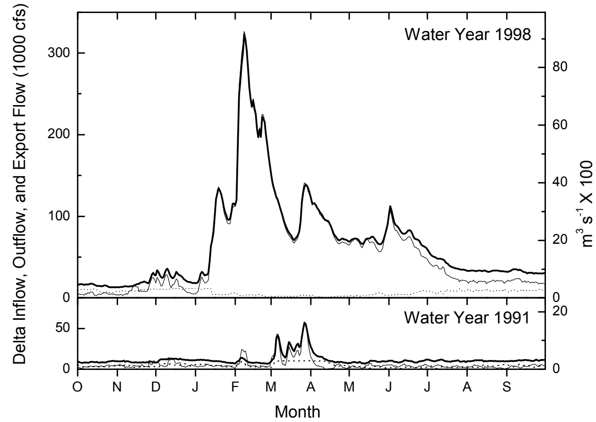


Figure 5 Delta inflow (heavy line), outflow (thin line), and export flow (dotted line) for two example water years of wet (1998) and critically dry (1991) hydrology

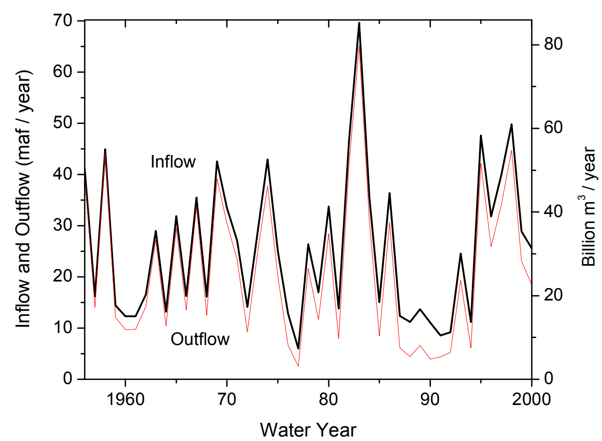


Figure 6 Total annual inflow and outflow by water year. Source: DWR DAYFLOW.

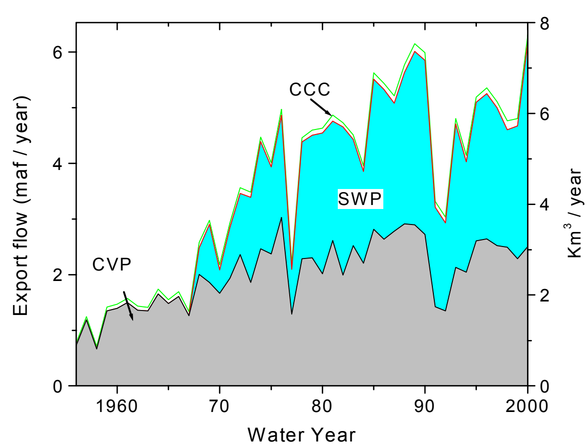


Figure 4 Export flow by water year, including the Central Valley Project, State Water Project, and Contra Costa Canal. Source: DWR DAYFLOW.

The San Francisco Estuary

The San Francisco estuary forms a continuous system linking freshwater inflows with the coastal ocean, but it is convenient to divide the estuary into discrete basins (Figure 7). For all intents, allocation of EWA resources focused on processes and biological components of the estuary east of the Carquinez Strait. We therefore limit our description to the Sacramento–San Joaquin Delta and the Suisun–Grizzly–Honker Bay complex.

The interaction of the seasonally varying inflows, tidal flows and topography result in a complex and not completely understood ecosystem that is important economically, environmentally, and socially. It is beyond the scope of this report to completely describe this system and the reader is referred to several references for more complete descriptions (for example, Conomos 1979; Herbold and others 1992; Hollibaugh 1996).

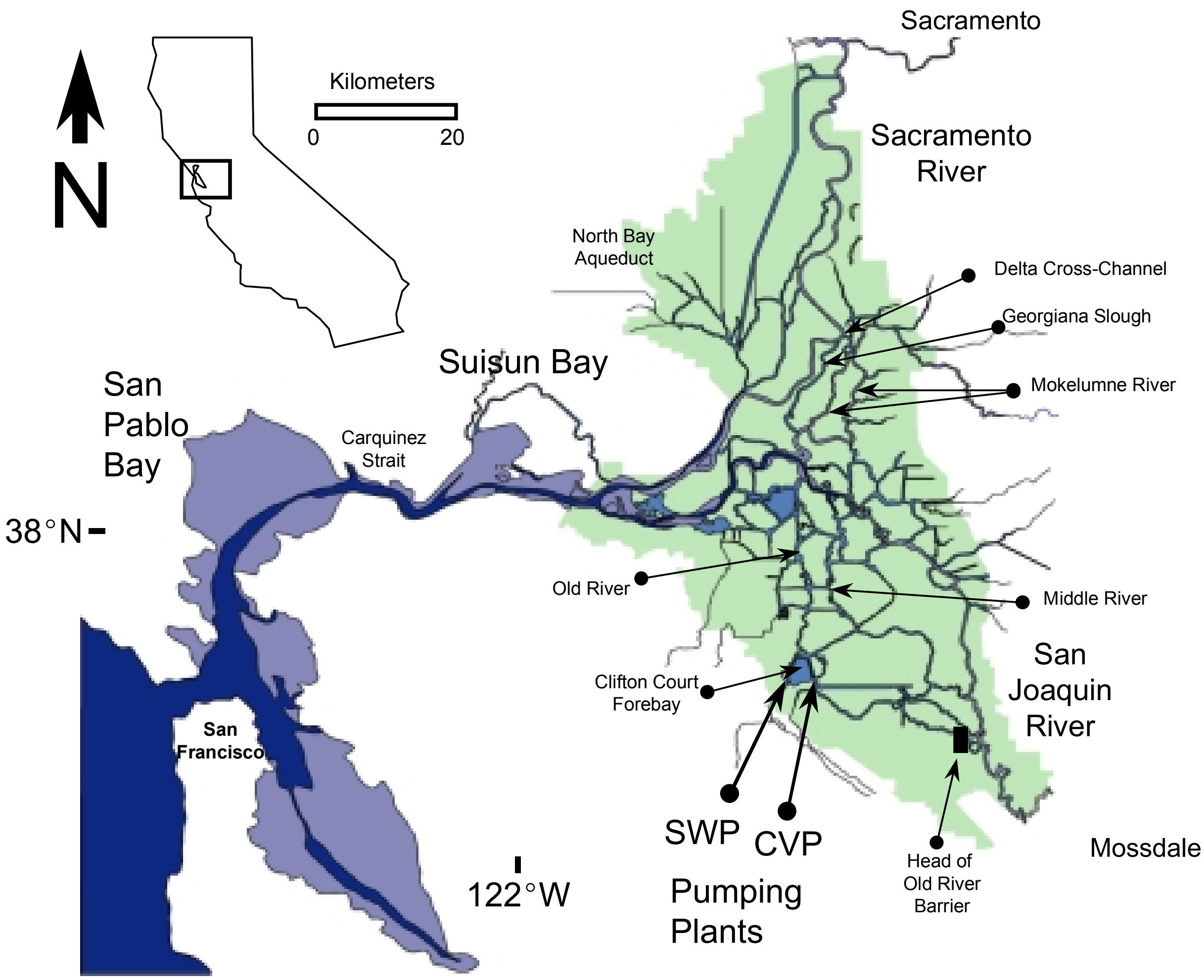


Figure 7 Map of the San Francisco Estuary showing discrete basins and other hydrologic features discussed in the text, including the Sacramento–San Joaquin River Delta (shaded area).

The Sacramento–San Joaquin Delta

Historically the Delta consisted of sloughs, channels, and marshes at the confluence of the Sacramento and San Joaquin rivers and some smaller streams such as the Mokelumne, Cosumnes and Calaveras rivers. In the 1850s, the Delta began to change substantially as immigrants to California built levees to isolate land from water. With construction of dams in the watershed, water began to be diverted from the Delta late in the 19th century. Projects on the Tuolumne, Merced, Mokelumne and other streams stored water for use by farmers and local and Bay area urban water users. The Central Valley Project began directly diverting water from the Delta in 1940.

Today the Delta is a series of leveed islands separated by channels, some of which have been altered for shipping and to increase the flow of freshwater for agricultural use and export. About 92% of the Delta's 738,000 acres is land and the remainder is open water. It is likely that less than 5% of the present Delta resembles the 1850 system. Much of the Delta land is devoted to agriculture, with the primary crops being corn and other grains, hay, alfalfa, sugarbeets, pasture, tomatoes, asparagus, safflower, and fruit. In 1990 the estimated value of these crops was over $500 million (DWR 1993). In addition to the large CVP and SWP diversions and the smaller Contra Costa Water District diversion in the south Delta, more than 2200 mostly unscreened, small agricultural diversions withdraw water from the Delta for irrigation (Herren and Kawasaki 2001).

The Delta is permanent or temporary home for more than 45 species of fish (Table 1) and a supporting community of benthic and planktonic organisms, as well as marshes and macrophytes. Many of the dominant fish species (for example, striped bass, white catfish, largemouth bass) are introduced and may compete with or consume native fishes. Delta water is turbid and poor light penetration limits primary production. There is some indication that turbidity is decreasing, which if continued could result in increased algal growth. The Delta is affected dramatically by inter- and intra-annual changes in inflow with generally depressed abundance of native fishes in drier years, as seen during the 1987–1992 drought. Superimposed on all of this is water management from dams and diversions in the watershed to direct diversions from the Delta. All of these factors and others affect decisions on use of EWA assets.

Table 1 Fish species collected at Skinner Fish Facility, 1979–1993[a]

Common name	Scientific name	Introduced (I) or Native (N)
Chinook salmon	*Oncorhynchus tshawytscha*	N
Steelhead rainbow trout	*Oncorhynchus mykiss*	N
Striped bass	*Morone saxatilis*	I
White catfish	*Ameiurus catus*	I
Brown bullhead	*Ameiurus nebulosus*	I
Yellow bullhead	*Ameiurus natalis*	I
Black bullhead	*Ameiurus melas*	I
Channel catfish	*Ictalurus punctatus*	I
Blue catfish	*Ictalurus furcatus*	I
Black crappie	*Pomoxis nigromaculatus*	I
White crappie	*Pomoxis annularis*	I
Green sunfish	*Lepomis cyanellus*	I
Bluegill	*Lepomis macrochirus*	I
Largemouth bass	*Micropterus salmoides*	I
Smallmouth bass	*Micropterus dolomieu*	I
Warmouth	*Lepomis gulosus*	I
Redear sunfish	*Lepomis microlophus*	N
Tule perch	*Hysterocarpus traski*	N
Sacramento perch	*Archoplites interruptus*	N
American shad	*Alosa sapidissima*	I
Threadfin shad	*Dorosoma petenense*	I
Splittail	*Pogonichthys macrolepidotus*	N
Sacramento squawfish	*Ptychocheilus grandis*	N
Hardhead	*Mylopharodon conocephalus*	N
Golden shiner	*Notemigonus crysoleucas*	I
Carp	*Cyprinus carpio*	I
Hitch	*Lavinia exilicauda*	N
Sacramento blackfish	*Orthodon microlepidotus*	N
Goldfish	*Carassius auratus*	I
Sacramento sucker	*Catostomus occidentalis*	N
Threespine stickleback	*Gasterosteus aculaetus*	N
Longfin smelt	*Spirinchus thaleichthys*	N
Delta smelt	*Hypomesus transpacificus*	N
Wakasagi[b]	*Hypomesus nipponensis*	I
White sturgeon	*Acipenser transmontanus*	N
Green sturgeon	*Acipenser medirostris*	N
Inland silverside[c]	*Menidia beryllina*	I
Yellowfin goby	*Acanthogobius flavimanus*	I
Chameleon goby[d]	*Tridentiger trigonocephalus*	I
Prickly sculpin	*Cottus asper*	N
Staghorn sculpin	*Leptocottus armatus*	N
Riffle sculpin	*Cottus gulosus*	N
Bigscale logperch	*Percina macrolepida*	I
Starry flounder	*Platichthys stellatus*	N
Lamprey	Various Species	N
Mosquitofish	*Gambusia affinis*	I
Pacific herring	*Clupea pallasii*	N

a.Source: Brown and others 1996.
b.Identified by Johnson Wang. Electrophoretic confirmation pending.
c.Also called Mississippi silverside.
d.According to Scott Matern, UC Davis, two species are actually present: *T. trigonocephalus and T. bifasciatus*.

Suisun–Grizzly–Honker Bay Complex

In this relatively shallow system, tidal currents and freshwater interact to form an ecologically rich mixing zone. For the early life stages of some fish, such as delta smelt and striped bass, successfully reaching and remaining in Suisun Bay may benefit subsequent year class strength. Habitat conditions appear to be favorable in Suisun Bay, and fish are less vulnerable to Delta export pumps the further they are from the pumps. These factors may be important in determining the relationships of abundance of some species to X2.

As in the Delta, environmental conditions in Suisun Bay are affected by freshwater and tidal flows. The principal influence of freshwater flow on Suisun Bay is to alter salinity, which in turn can alter salinity stratification in deeper regions, and change residence time. The interaction between flow and X2 or salinity is well understood, but the mechanisms by which these affect various species have not been determined.

Conditions in Suisun Bay have changed over the past 2 or 3 decades. There has been a decrease in spring and early summer algal standing crop, which has been attributed to climate change (Lehman 2000) and to grazing by an Asian clam, *Potamocorbula amurensis*, introduced in 1986 (Alpine and Cloern 1992; Kimmerer and others 1994). Declines in copepods, mysids, and some fish may be a result of the high rate of filter-feeding by this clam, which has eliminated the summer-long phytoplankton blooms once characteristic of Suisun Bay (Kimmerer and Orsi 1996; Kimmerer 1998).

Delta Hydrodynamics

Understanding movement of water in the Delta is critical to understanding fish movement, although key aspects of fish behavior are as yet poorly understood. Flow in the Delta is an amalgam of river-derived net flow and tidal oscillation. The relative magnitudes of net and tidal flow depend on location and river flow, with greater tidal dominance toward the west and at lower river flow. For example, at various locations in the south Delta, tidal volume flow rates were about 3 to 10 times net flows during the spring 1997 VAMP period of reduced exports (Oltmann 1998). At the western margin of the Delta, however, tidal flows are about 50 to 100 times net outflow at low to moderate river flow.

Tidal flows oscillate, but through the interaction with the complex geometry of the Delta and Suisun Bay, they can produce net flows independent of the river and can cause extensive mixing. Mixing by the tides requires a gradient; for example, salt is mixed upstream into the Delta mainly by the interaction of tidal mixing with the salinity gradient. Similarly, differences in concentration of any substance in the Delta cause that substance to be mixed in a direction to eliminate the differences.

For purposes of this discussion, the main interest in Delta hydrodynamics arises because of the influence of hydrodynamics on fish. That influence is largely a matter of speculation, except for experiments on salmon. Experiments with coded wire-tagged smolts have shown the importance of flow in the Sacramento River and position of the Delta Cross Channel gates (see Figure 7 and "Delta Cross Channel" section on page 22), as well as possible effects of export flow (Brandes and McLain 2001). More recent experiments used sonar or radio-tagged yearling salmon smolts to investigate how hydrodynamics affects these fish. The most prominent result was the importance of tides in affecting where the fish went, although in the Delta Cross Channel study the initial movement of the fish released in the Sacramento River was with the river flow (Herbold, personal communication, see "Notes").

The influence of hydrodynamics on other fish is unknown, but probably depends on the size of the fish, whether they are migrating through the Delta or residing there, and their habitat use. For example, early delta smelt larvae in the open water probably move mostly with the tides, whereas salmon fry use shallower habitat and are less subjected to tidal or net currents.

During high flow periods, water flows into the Delta from the Sacramento, San Joaquin, and other smaller rivers, and exits the Delta into Suisun Bay as net Delta outflow. During most summers, flow in the San Joaquin River is lower than export flows in the southern Delta, so water is released from reservoirs feeding the Sacramento River to provide flow for export and to meet salinity and flow standards in the Delta. Under these conditions, most of the freshwater in the Delta originates in the Sacramento River.

The proportion of freshwater entering the Delta that is subsequently exported during the dry season (June through September) has a median of 38% over the last 30 years, with 90th percentiles of 20% and 54%. Channel depletion, an estimate of consumptive use in the Delta, has a median value of 18% of total inflow in the same period, with 90th percentiles of 10 and 35%. Gross consumption, the actual amount removed from the estuary, has been estimated as about one-third higher than net consumption (DWR 1995).

The above comparison of export flow to inflow may be inappropriate, given the dispersive conditions during low flow periods. A more appropriate comparison may be between absolute diversion flows and total Delta volume, which would scale the risk of a particle being exported in a day if the Delta were well mixed. Daily export flows range up to 2.8% of Delta volume in summer, but most of the time in summer the fraction of Delta volume exported daily amounts to less than 2%. Channel depletion flows (that is, net intake by Delta farms) average about half this value in summer. These export and diversion flows may have a considerable cumulative effect on slowly growing resident biota but are unlikely to affect populations with high turnover rates such as phytoplankton (turnover rate about 10% to 50% per day) or zooplankton (turnover rate about 10% to 20% per day).

Conceptual models of flow patterns in the Delta have shifted markedly over the last decade (Figure 8, shown in 3 parts A, B, and C). The earlier view (Figure 8A) held that calculated net flows such as QWEST (net flow in the San Joaquin River at Jersey Point) were important in determining the movement of substances and organisms. According to this perspective, the pattern of net flows in the Delta moves substances and guides the movement of fish. A commonly used figure (for example, Figure 9 in Ball and Arthur 1979) shows net flow directions calculated for each major channel in the Delta. The more recent view (Figure 8B) sees the Delta as a region of transition between riverine and tidal flows. The shift of perspectives on flow in the Delta has arisen mainly through the development of two tools: particle tracking computer models of the Delta, and direct measurement of flow velocities and volume transport at various locations in the Delta.

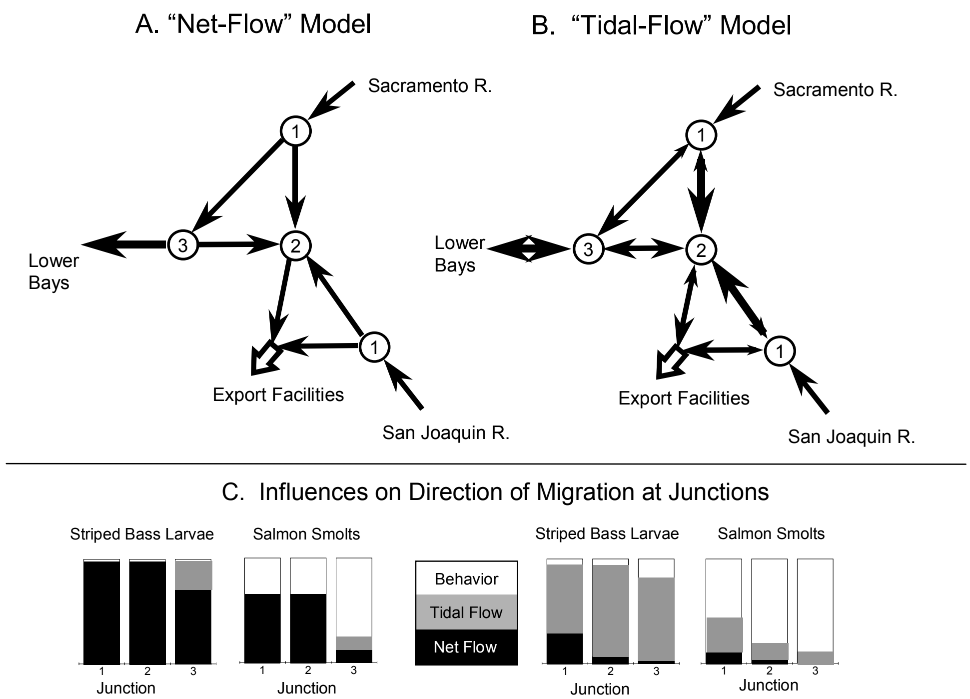


Figure 8 Conceptual model of flow patterns in the Delta and their consequences for movements of fish. A and B, schematic diagrams of the Delta with representative channels and nodes: 1, points of entry of Sacramento and San Joaquin rivers into Delta; 2, lower San Joaquin River at junction with Old and Middle rivers; 3, western Delta at confluence of rivers. A, "Net-flow" model showing directions of calculated net flows; B, "Tidal-flow" model in which double-ended arrows indicate tidal flows, with the relative sizes of arrowheads indicating relative magnitudes of flows in each direction; C, Qualitative depiction of influence of these alternative models on expected movements of early striped bass larvae and salmon smolts. Each bar shows the relative importance of fish behavior, net flow, and tidal flow in moving fish past each of the numbered junctions.

Several particle tracking models of the Delta have been developed. Until recently all of them used a simplified one-dimensional representation of Delta channels. Although the one-dimensional models may be inaccurate in their depiction of the details of particle or substance transport, the general patterns arising from these models have at least heuristic value, and their predictions may be accurate enough for many purposes. Unfortunately, to date there has been little published using these models. Enright and others (1996) showed results of simulations of movements of contaminants that matched the data quite well within the Delta.

The general trend of model results seems to be that a patch of particles released in the Delta will move generally in the direction of net flow, but with extensive spreading of the patch due to tidal dispersion. The export pumps in the south Delta and the agricultural diversions impose a risk that a particle will be lost from the system. This risk increases with diversion flow, initial proximity of the particle to the diversion, and duration of the model run. In a model run to examine the suitability of QWEST as an indicator of flow conditions for management, it was found that computed reverse flows (negative QWEST) had at most a minor effect on the entrainment of neutrally buoyant particles, which was better predicted by the absolute magnitude of export flow. Thus, the earlier concept by which salmon smolts and other fish were "sucked" up this part of the Delta toward the pumps does not match the reality of flow in this region, which is dominated by tides under low flow conditions; of course it never matched the behavior of fish.

Using acoustic doppler current profilers (ADCPs) and ultrasonic velocity meters, Oltmann (1995, 1998) measured tidal flow volume in the Delta accurately enough to calculate tidally averaged net flows. Results of these measurements and calculations generally suggest that tidal effects are important in net transport. For example, net flows in the various pathways toward the water project pumping plants were not greatly affected by the sign of net flow in the lower San Joaquin River, although they responded to the installation of a barrier at the head of Old River (Oltmann 1995). In addition, net flow through Threemile Slough in the western Delta was generally from the Sacramento River to the San Joaquin River because of differences in tidal phase, except during very high flow in the San Joaquin River. Net flow in the Sacramento River was higher upstream and decreased downstream of the Delta Cross Channel when the gates were open compared to when they were closed. Net Delta outflow, estimated as the sum of net flows at four stations in the western Delta, was close to that calculated by mass balance at high freshwater flow, but diverged substantially at low flow as spring-neap filling and draining and meteorological effects on water level became apparent (Oltmann 1998). A study using a spatially detailed two-dimensional model has also shown that under low flow conditions daily net Delta outflow is a crude measure of flow patterns in the western Delta, which are strongly affected by the spring-neap tidal cycle (Monsen 2000). Dye studies showed that longitudinal dispersion was of similar importance to net flow in the movement of dye patches (Oltmann 1999).

The importance of the contrast between the two conceptual models described in Figures 8A and 8B can be seen in the consequences for fish movement depicted in Figure 8C. If the “Net-flow” model is assumed, then relatively passive organisms such as early striped bass or delta smelt larvae should move largely under the influence of net flows, with an increasing behavioral component of motion as the fish develop. Larger, strongly swimming salmon smolts are more capable of moving independently, but they too would be affected to some degree by net flow. According to the “tidal-flow” model, striped bass larvae would be influenced most by the interaction of their behavior with tidal flows, and only slightly by net flows, once they were in the Delta. Salmon smolts would be able to control their location, but with a strong influence by tidal flow; net flow would probably affect them indirectly by setting up cues for finding the ocean. The difference in the consequences for movement of these fish through the Delta are clear (Figure 8).

Water Project Operations and Facilities

This section provides a brief description of some of the state and federal facilities used to store and move water though Central Valley streams and the Delta. We also describe some of the facilities and agreements that are intended to help mitigate for water project effects. A more complete description is found in DWR and USBR (1994, 2000) and DWR (1998).

The federal Central Valley Project (CVP) began in the 1940s with construction of Shasta Dam and the Contra Costa Canal with its diversion point in the western Delta. Other major features, including Folsom Dam, the Delta Cross Channel, Friant Dam, Delta pumping facilities near Tracy and the Delta-Mendota Canal followed in the 1940s and 1950s. The Trinity Project, completed in 1963, was designed in part to augment Central Valley water supplies through a connection from the Trinity River to the Sacramento River system.

The State Water Project (SWP) was authorized by California voters in 1959 and began storing water in the Feather River and pumping water from the Delta in the late 1960s. Construction of the SWP included two significant joint use facilities, the San Luis Canal (a portion of the California Aqueduct that begins at O’Neill Forebay and extends nearly 101 miles south to pool 21) and the San Luis Dam and Reservoir complex, which provided storage and operational flexibility for both water projects.

The CVP is complete, although existing facilities may be modified; for example, by raising Shasta Dam and constructing new fish protection facilities in the Delta. When constructing the SWP, planners considered the south Delta diversion a temporary solution and began planning for a permanent diversion point. This planning culminated in the early 1980s with a recommendation to move the diversion point to the Sacramento River near Hood (the Peripheral Canal). In 1982 the recommendation for this diversion and accompanying mitigation measures was put before voters and defeated.

The CVP provides water to agricultural and urban entities in the Central Valley and, by way of the San Felipe Project, to urban water agencies in Santa Clara County. Most of the delivered water is destined for agricultural uses. The CVP also provides water to refuges and, as a result of the 1992 Central Valley Project Improvement Act, allocates up to 800,000 af annually for environmental purposes. Between 1980 and 2000 the CVP has provided an average of 2.4 million acre-feet (maf) to its contractors. The SWP provides water for agricultural users in the Sacramento Valley and southern San Joaquin Valley and to urban users in the San Francisco Bay area, the Central Coast, and southern California. On average, the SWP has provided about 2.4 maf annually to its contractors, divided about equally between agricultural and urban users. At ultimate build-out, the SWP split is projected to be closer to 70% for urban and 30% for agricultural users.

The seasonal and interannual variation in precipitation, coupled with competing needs placed on the CVP and SWP for storage, streamflows, people, and fish, complicates water project operations. Balancing these complex needs requires managers to participate in a day-to-day process involving a myriad of decisions that must be overlaid on long-range operational plans. Each year DWR and USBR managers project potential water supplies and demands. This process generally begins in early fall and culminates in preliminary water delivery allocations for SWP and CVP contractors. These allocations are adjusted through the winter and early spring months as water supply and demand forecasts are updated.

In 1994, the federal and state governments signed the CALFED Framework Agreement. This watershed agreement established the three primary facets of CALFED: (1) the Bay-Delta Program was created to develop long-term and durable solutions for the Delta; (2) the SWRCB was to finalize water quality objectives and proceed with a new decision on standards to protect beneficial uses of water in the Bay-Delta; and (3) the CALFED Operations Coordination Group (Ops Group) was formed to facilitate operation of the CVP and SWP with implementation of the CVP Improvement Act and protection of endangered species. As activities proceeded on all three facets, operations of the SWP and CVP became more complex, requiring high-level coordination among the three management agencies (DFG, NMFS, and USFWS) and the two water project agencies (DWR and USBR). Today, those agencies meet on a regular basis through the Ops Group to review and discuss operations with stakeholders. The Ops Group process also provides a forum for these same agencies to address activities that require policy level input—the Water Operations Management Team (WOMT). WOMT meets regularly to review recommendations made by Ops Group sub-groups (such as the Data Assessment Team or the Operations and Fish Forum).

State Water Project Facilities

The following descriptions are keyed to the features shown in Figure 1. References listed in the introduction to this chapter provide more complete descriptions.

Oroville Dam and Reservoir

Oroville Dam was completed in 1967 and the resulting reservoir has the capacity of about 3.5 maf. The dam and reservoir complex provides for flood protection, recreation, hydroelectric generation, and water supply. Project water released to the Feather River flows through natural channels to the Delta where a portion can be pumped for project deliveries. Water released from Oroville takes about 3 days to reach the Delta. DFG and DWR entered into a 1983 flow agreement to protect instream environmental resources. DWR's Federal Energy Regulatory Commission's license for the Oroville complex expires in 2007 and a stakeholder-driven process is underway to review the license.

North Bay Aqueduct

This SWP facility, completed in 1988, can pump up to 170 cfs from a small, screened intake off Barker Slough in the north Delta. The diverted water is used to meet SWP demands in Solano, Napa, and Sonoma counties. Generally EWA actions do not affect this diversion. High catches of delta smelt near the intake may result in pumping restrictions independent of the EWA.

South Delta Temporary Barriers Project

This is a joint DWR–USBR project in the South Delta designed to help alleviate low water levels caused by SWP and CVP operations, in particular Delta diversions. Since low water levels make it difficult for farmers to obtain water from Delta channels to ameliorate project effects, DWR installs up to three rock barriers (Grantline Canal, Middle River, and Old River near Tracy) during the summer months. These barriers have culverts with flapgates to allow flow and fish movement when needed. In addition, a fourth rock barrier, at the head of Old River, may be installed as a fish mitigation barrier. When in operation the head of Old River barrier acts to keep downstream migrating salmon in the San Joaquin River, increasing their chances of reaching the ocean. The EWA action process may result in the flapgates being tied in the open position or one or more of the barriers being removed completely.

Clifton Court Forebay

DWR constructed this approximately 30,000 af regulatory reservoir at the intake to its southern Delta diversion. Operationally, the gated forebay takes water near high tides and, by keeping the reservoir water level more or less constant, allows DWR to maintain relatively steady flow (and velocity) through its fish protection facilities. As will be seen later, the down side to this operation is that the Forebay provides good habitat for predators, such as striped bass, which consume fish that would otherwise be salvaged. While the facility is permitted by the State Water Resources Control Board to divert up to 10,300 cfs, other regulatory considerations generally restrict the average daily inflow to about 6,700 cfs[1]

John E. Skinner Fish Protective Facilities

These facilities are located in front of SWP pumps and are designed to separate fish from the water being diverted. The original facilities, constructed in the mid-1960s, consisted of a set of primary and secondary louver-type fish screens. The louvers were constructed in a downstream pointing V-shape, with the space between the louvers (slats) being about 1 inch. In the late 1960s DWR and DFG evaluated screen efficiency, which depended on the fish being able to sense the turbulence created by flow past the slats, for chinook salmon and striped bass. Efficiency was relatively high for fish longer than the one-inch slot width. Fish remaining in the V move down to a bypass at the lower (narrow) end and enter a bypass, which takes them to a secondary screening system (to further concentrate them) and thence to holding tanks. Operators periodically count samples of fish in the holding tanks, identify them to species, and load them at least once daily into tanker trucks for transfer to release sites away from the direct influence of the pumps. In the mid-1980s DWR modified the fish facilities by adding a new positive barrier secondary screen and a new holding tank building. These modifications were to increase the facilities' capacity and salvage efficiency as four new pumps were brought on line.

1. The existing agreement between DWR and U.S. Army Corps of Engineers allows Clifton Court Forebay inflow to exceed 6,680 cfs from mid-March when the San Joaquin River flow exceeds 1,000 cfs.

Harvey O. Banks Pumping Plant

The SWP Delta pumping plant, located about 1 mile downstream of the fish protection facilities, has the capacity to lift up to 10,300 cfs 244 feet into the California Aqueduct. The pumping plant has 11 pumps with individual capacities ranging from 375 to 1,067 cfs, providing considerable operational flexibility. Coupled with operation of Clifton Court Forebay, the extra capacity at Banks allows DWR to pump during the evening and late night off-peak hours—a pumping scenario that can lower energy cost, but one that can affect operation of the fish protection facilities.

California Aqueduct

Water pumped from the Delta enters the approximately 500-mile long, concrete-lined California Aqueduct and flows by gravity to a series of pumping (relift) plants to downstream turnout facilities and storage reservoirs. Initial aqueduct capacity is about 12,000 cfs. The canal between the San Luis Reservoir complex and pool 21, some 101 miles south, is for joint CVP and SWP use.

San Luis Dam and Reservoir

The joint use San Luis complex (which includes the relatively small O'Neill Forebay) plays a key role in Delta operations. The approximately 2 maf reservoir provides off-stream storage for water pumped from the Delta. (There is relatively little contribution from its watershed.) Reservoir storage is split about evenly between the CVP and SWP and water released from the reservoir is used to meet water demands. The basic goal is to fill the reservoir during winter and spring months and to use stored water in the summer and fall. The "San Luis low point" figures prominently in that the USBR attempts to keep a minimum summer storage level that minimizes water quality problems in water delivered to Santa Clara County. The San Luis Reservoir can also be used to store water purchased for the Environmental Water Account.

Facilities Downstream of San Luis Reservoir

Several pumping plants and storage reservoirs are used to move and hold water used by Kern County, Central Coast and southern California users. These facilities, shown in Figure 1, are essential to SWP operation. They also have direct bearing on the EWA because of the source-shifting agreement between the Metropolitan Water District of Southern California and the EWA.

State Water Project Mitigation

In this context we use the term mitigation to denote those aspects of SWP operation that cannot be avoided by changes in project operation. For example, under this definition, fish screens are considered avoidance and minimization measures. To the extent that all fish losses could not be avoided, measures have been taken to mitigate the unavoidable losses. Two SWP mitigation measures are described below:

Feather River Hatchery

DWR constructed the Feather River Hatchery (FRH) in the mid-1960s to mitigate for salmon spawning habitat lost above the Oroville Dam site. (No fish ladders were built to move salmonids over the 600-ft dam.) In the years immediately before dam construction there was a small spring run of chinook salmon that spawned in the upper reaches of at least one of the Feather River forks; a small steelhead run that also spawned in the headwaters; and robust fall chinook salmon run that mostly spawned near the dam site. The hatchery, operated by DFG, propagates spring and fall chinook and steelhead. Most spring and fall run production is trucked to near the Carquinez Strait for release. A significant percentage of spring and fall production is marked with coded wire tags to help evaluate the hatchery's contribution to the ocean fishery, escapement to the Feather River and straying to other streams. All tagged salmonids, at the Feather River hatchery and elsewhere, are also marked by having the adipose fin clipped off so that a tagged fish can be readily distinguished from an untagged fish that may have been spawned naturally. All hatchery steelhead production is released in the Feather River and is marked with an adipose clip and a coded wire tag.

Delta Pumping Plant Mitigation Agreement (4-pumps Agreement)

In 1986 DWR and DFG signed this agreement to mitigate for the installation of 4 additional pumps at the Delta pumping plant. The agreement calls for estimating the losses of steelhead, chinook salmon and striped bass and funding projects to offset these losses. These projects have ranged from stream improvements (for example, gravel restoration), constructing fish screens, funding wardens to minimize poaching, and hatchery production for striped bass and steelhead. In this agreement, DFG and DWR developed a method for calculating losses of striped bass, chinook salmon and steelhead in the Clifton Court Forebay. At the time, the best estimate of the loss of chinook salmon in Clifton Court Forebay was 75%; that is, for each salmon collected at the fish facility it is estimated that three salmon were killed in the Forebay, presumably by predators. Although subsequent experiments have indicated that this loss rate may be conservative, it is still used in calculating salmon losses at the SWP intake.

Central Valley Project Facilities

This summary solely provides some highlights of CVP facilities, thus, the reader is encouraged to refer to the reference material for more information. In addition, a well-written general guide to the CVP can be found in Water Education Foundation (1998).

Shasta Dam and Reservoir

Shasta Dam, completed in 1945, impounds about 4.5 maf of Sacramento water at full storage. The dam and reservoir complex provides for flood protection, recreation, hydroelectric generation, and water supply. Water released from Shasta Dam takes about 5 days to reach the Delta. A complex system of natural hydrology, environmental needs, hydropower requirements, and project demands regulate releases of Sacramento River water from Shasta Reservoir. In 1997, the USBR installed a temperature control device in the reservoir to help access colder water for summer-spawning winter-run chinook salmon.

Keswick Dam and Reservoir

Keswick Dam is located near the town of Redding a few miles below Shasta Dam. Keswick Reservoir acts as a small regulating reservoir to help moderate flows from Shasta. The federal government operates a fish trap at Keswick to trap adult winter chinook for a conservation hatchery program. There are no fish ladders at Keswick Dam, so it is the terminal dam on the Sacramento River.

Trinity River Project

Although geographically outside the Central Valley, dams and reservoirs on the Trinity River are connected to the Sacramento River system through Whiskeytown Reservoir and Clear Creek. On an annual average the Trinity River Project has contributed about 1 maf to Sacramento Valley water users. Fishery issues in the Trinity system may affect future transfers to the Central Valley.

Red Bluff Diversion Dam

The USBR built the Red Bluff Diversion Dam (RBDD) in the mid-1960s to raise water levels in the river so that water could be diverted by gravity into the Tehama–Colusa Canal. The dam included the capability of raising gates so that the Sacramento River could freely flow downstream. When the gates were down, fish ladders were to allow upstream passage of adult salmon and steelhead. (Note that all four races of Central Valley chinook salmon spawn upstream of the RBDD.) Fish studies indicated that the RBDD caused significant impacts to movement of adults and juveniles. Biological opinions have subsequently caused the dam gates to be down only from May 15 to September 15. Since 1967 adult salmon counts at the fish ladder have been used to estimate chinook salmon and steelhead escapement. With the dam gates now raised most of the year, the ladders are inoperative, resulting in the complete loss of escapement figures for late fall chinook and questionable estimates for winter chinook escapement.

Folsom Dam and Reservoir Complex, Including Nimbus Dam and Lake Natoma

The USBR completed Folsom Dam, located on the American River, in 1956. Folsom reservoir has a capacity of about 1 maf and water released from the reservoir can be in the Delta in a matter of hours. Its proximity to the Delta makes Folsom Dam a convenient water source when concerns over water quality or other issues in the Delta require additional project releases. The reservoir has a limited cold water pool and relatively small total storage, and runs of fall chinook and steelhead occur in the Lower American River; thus potential releases for Delta protection must take in-river environmental protection into consideration. Fish blockage occurs at Nimbus Dam, located about 7 miles downstream of Folsom.

Delta Cross Channel

The USBR constructed the gated Delta Cross Channel in the early 1950s to facilitate movement of Sacramento River water across the Delta to its pumping plant in the south Delta. The original operation consisted of keeping the gates open when flows in the Sacramento River would not threaten non-project levees in the Mokelumne River system. (This generally occurred when flows were less than about 30,000 cfs.) With the gates open, interior Delta water quality remained good and boaters had access to the Mokelumne River system and the rest of the Delta. Studies conducted by the Interagency Ecological Program (IEP) indicated that survival of outmigrating juvenile salmon decreased when the gates were open. In response to this finding, the 1992 and subsequent winter chinook biological opinions (and the State Water Board's Water Quality Control Plan) require that the gates to be closed from February 1 through about May 20 each year. At the discretion of the managing agencies, the gates may be closed for and additional 14 days between May 21 and June 15, and up to 45 days between November 1 and January 31. In addition, the gates may also be operated outside of the Water Quality Control Plan in support of data collection on the effects of gate operation on Delta water quality and fish migration. These experiments generally take place in late summer and early fall.

Tracy Fish Protective Facilities

These facilities, constructed in the early 1950s, screen and salvage the majority of fish entering the intake to the USBR's Delta–Mendota Canal. As with the SWP's fish facilities, operators periodically estimate the numbers and species of fish being salvaged and transport salvaged fish to release sites in the Delta. Unlike the SWP, there is no forebay in front of the CVP intake, so water level constantly changes in the screen channels. In addition, the lack of a forebay has been used to arrive at a 15% pre-screen loss of salmon entering the salvage facilities. Unlike the SWP, there have been no studies to document the CVP pre-screen loss rate.

Tracy Pumping Plant

The pumping plant, completed in 1951, is located about 1 mile downstream of the fish facilities and has a maximum capacity of about 4,600 cfs. The pumping plant consists of 6 individual units with capacities ranging from 800 to 950 cfs that lift water about 197 ft into the Delta–Mendota Canal. Under normal conditions, the Tracy Pumping Plant exports near capacity around the clock.

Delta–Mendota Canal

Originally the USBR used the Delta–Mendota Canal (DMC) to move Delta water to the Mendota pool. The canal provided water to water rights holders along the San Joaquin River that had lost access to water when the Bureau completed the Friant Project on the San Joaquin River near Fresno. There is now also an intertie allowing water in the DMC to be moved to San Luis Reservoir for storage.

Central Valley Project Mitigation

As with the SWP, the CVP has significant project mitigation features. Four of them are described below.

Coleman National Fish Hatchery

Since Keswick Dam completely blocked salmonid access to the upper Sacramento River, the CVP authorized construction of the Coleman National Fish Hatchery (CNFH). In the hatchery, located on Battle Creek near the town of Red Bluff, the USFWS now rears fall chinook and steelhead for release in the river. (Winter chinook were formerly reared and released there.) The hatchery and its practices are undergoing a thorough analysis to evaluate their effect on listed salmonids.

Livingston Stone National Fish Hatchery

This small new facility, opened in 1998, is devoted exclusively to the culture of winter chinook. This endangered race was formerly spawned and reared at the CNFH but tagging studies indicated that the adults were returning to the Battle Creek hatchery rather than spawning in the river. The Livingston Stone National Fish Hatchery is located at the base of Shasta Dam so the rearing fish imprint on Sacramento River water. Broodstock collection is limited to reduce chances of adversely affecting genetic integrity of winter chinook.

Nimbus Fish Hatchery

The Nimbus Fish Hatchery is located just below Nimbus Dam on the American River and serves to mitigate upriver spawning habitat lost when Folsom Dam was closed. DFG operates the hatchery to produce fall chinook and steelhead. All chinook production is released as smolts near Carquinez Strait.

DFG–USBR Tracy Pumps Mitigation Agreement

In the early 1990s DFG and the USBR signed an agreement to mitigate for the direct losses of chinook salmon, striped bass, and steelhead due to CVP pumping from the south Delta. Although patterned somewhat after the earlier DWR–DFG agreement for the SWP pumps, the USBR–DFG agreement emphasizes projects, rather than attempting to mitigate for specific numbers of fish lost.

Fish of Special Concern in EWA Actions

In this chapter we describe some relevant features of several native species and runs of fish that often were the focus of EWA actions. The descriptions are kept relatively brief and references provided for more complete information. The species are: four races of chinook salmon (*Oncorhynchus tshawytscha*) endemic to California's Central Valley; steelhead rainbow trout (*O. mykiss*); delta smelt (*Hypomesus transpacificus*), splittail (*Pogonichthys macrolepidotus*) and green sturgeon (*Acipenser medirostris*). The general pattern is to provide a conceptual model then to summarize the listing status and history of each species and some key life history characteristics, provide some current and historical abundance estimates, and list characteristics that make them vulnerable to Delta conditions, including water project operations. For chinook salmon and steelhead, we provide some general information on hatchery production—an important contributor to the abundance of at least three of the four races.

We emphasize that there are more than 45 species of fish inhabiting the Sacramento–San Joaquin Delta (Table 1) and another 60 or so species found in the downstream embayments. These fish are supported by a complex ecosystem of freshwater and tidal forcing and producers and consumers—a constantly changing ecosystem that is affected by a multitude of natural and humaninduced factors. In this first year of the EWA, the focus was on the fish species of special concern but the EWA is intended to operate as part of a system of projects and actions leading to ecosystem restoration. We anticipate that future EWA reviews will focus less on specific fish and more on ecosystem effects.

Chinook Salmon

Healey (1991) provided the definitive description of this pan-arctic species—one of seven species of Pacific salmon. Although there may have been other species of Pacific salmon in the Central Valley and tributaries, chinook salmon is the only one now commonly found. Yoshiyama and others (2001) used a variety of sources to summarize the species' historical distribution. Dams and other human perturbations have dramatically reduced the amount of habitat available for chinook spawning and rearing. In some instances, hatcheries were constructed and operated to mitigate for spawning and rearing habitat lost above major high dams.

Four runs of chinook salmon are endemic to Central Valley rivers and tributaries: the winter, spring, fall and late fall runs. The names indicate the seasons in which adults enter freshwater on their spawning migrations. Historically the runs were separated either temporally or spatially and admixtures were relatively rare. Recent genetic analyses demonstrated that the winter run is quite distinct, the spring run reasonably distinct, and the fall and late fall runs genetically similar (Figure 9). However, there are phenotypic differences between fall and late fall runs, with many distinct runs returning to their natal streams. This phenotypic difference is of particular importance on San Joaquin tributaries, where run sizes have typically been lower and more variable than those in Sacramento Valley streams.

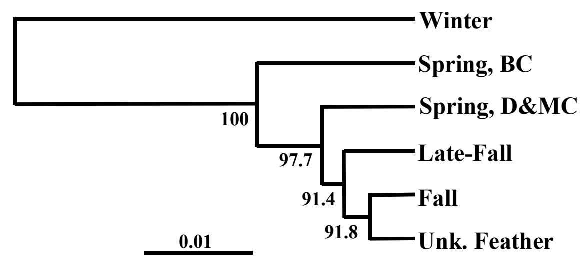


Figure 9 Genetic characterization of Central Valley chinook salmon. BC = Butte Creek, D = Deer Creek, MC = Mill Creek. Unk. Feather = unknown Feather River. Source: Hedgecock and others 2001.

The following information is condensed from an unpublished report on modeling chinook salmon populations in the Sacramento basin (Kimmerer, unpublished). Chinook salmon are anadromous fish, migrating from freshwater to marine environments early in their life, maturing in the ocean, and returning inland to spawn in freshwater streams and rivers (Figure 10). Their life history patterns are flexible, allowing them to capitalize on good conditions when they occur. The homing abilities of adult chinook are well developed, apparently based on a combination of olfaction and vision. The time of imprinting to the natal stream may vary between the initial rearing period and the time immediately before smolting, so straying can depend on conditions during rearing; in addition, due to fish planting practices, hatchery fish may stray more than wild fish.

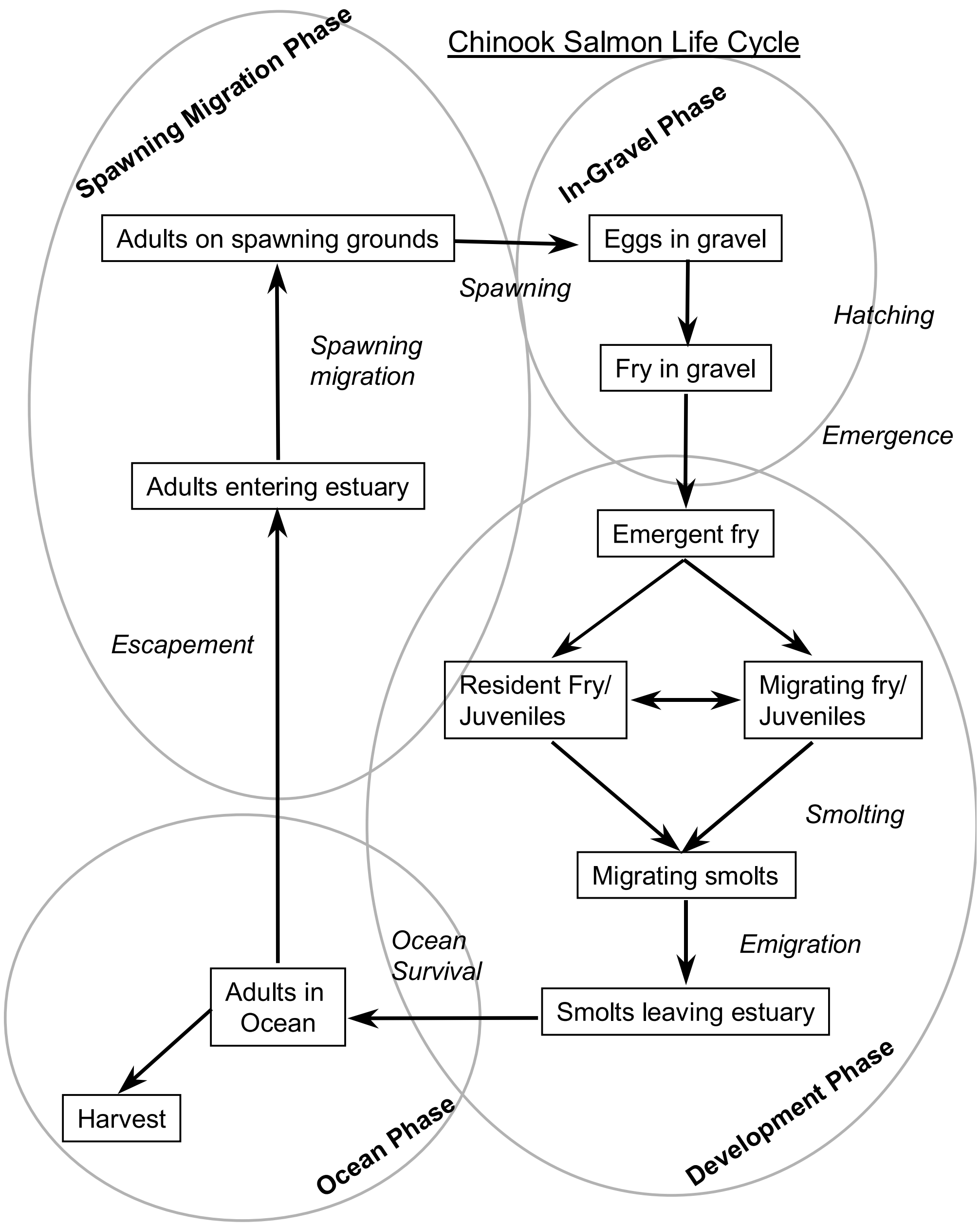


Figure 10 Summary of the life cycle of chinook salmon. The four oval areas represent the four major phases in the life cycle. Arrows indicate a change of state of surviving salmon, with only harvest mortality displayed explicitly. Terms in italics indicate the major transformations occurring in each phase.

Adult chinook salmon spawn in shallow redds (nests) constructed in relatively clean, loose gravel of 5 to 20 cm diameter, typically at the tail-end of pools and at the head of riffles. Although depth and velocity are used to define spawning habitat in the Instream Flow Incremental Methodology (IFIM, a procedure used to help define fish habitat needs, see for example Bovee 1982), these criteria alone can result in a large overestimation of the area of spawning habitat. Suitable substrate needs an adequate size distribution of the gravel and adequate subsurface flow for irrigation of redds during incubation. All adult chinook salmon die after spawning, although females may defend redds for a period of time before succumbing.

Superimposition may occur when a female salmon constructs a redd and, in doing so, disrupts an undefended redd causing mortality of eggs and alevins, resulting in density-dependent mortality. Fecundity and egg size are weakly related to size of the female. The eggs incubate within the gravel and hatch in approximately 6 to 12 weeks, after which the young fish (alevins) remain in the gravel for an additional 2 to 4 weeks until the yolk is absorbed. Survival can be as high as 97% if gravel is relatively free of fines and percolation rates are high, but declines sharply with poor percolation or low dissolved oxygen, which can occur under low-flow conditions. Flood flows can physically disrupt redds by moving gravel, also resulting in poor survival. High temperature can also result in poor survival of eggs, with the upper temperature for 50% survival at 16 °C.

Survival from hatching to emergence is not well documented. In the absence of floods sufficient to disrupt gravel, various studies have found that 10% to 20% of potential eggs (in other words, the sum of the eggs contained in spawners) survived to migrate downstream. Possibly because of reduced swimming ability, emerging fry are initially displaced downstream such that much of the fry production of streams in the Sacramento Basin rears elsewhere. Fry tend to seek shallow, nearshore habitat with slow water velocities and move to progressively deeper, faster water as they grow.

Juvenile chinook salmon feed primarily on insects in streams, and insects and crustaceans in estuaries. They may rear in their natal streams, in other parts of the river system including small creeks or sloughs, or in the estuary. Estuarine rearing seems to be important for many chinook salmon stocks. Although the proportion of annual juvenile production moving downstream to rear in lower river reaches and in the Delta is unknown, available information indicates substantial numbers of fry rear in the Delta, especially during wetter years. Growth rates generally are higher in estuaries compared to upstream habitats. Growth of young chinook salmon in the Yolo Bypass, a managed floodplain of the Sacramento River, was higher than in the river because of higher temperature and food availability (Sommer and others 2001b). Competition for food or habitat, of interest for its potential density-dependent effects, may be important especially for stream-type chinook such as spring run. Survival from fry to smolt ranges from approximately 3% to 50% generally in chinook (Healey 1991).

Juveniles may rear in freshwater or in estuaries for several months to over a year. Before migrating to the ocean, they undergo physiological and behavioral changes called smolting. The fish change body shape, becoming more slender, become silvery in color and tolerant of sea water, and tend to school. Smolting occurs at about

70 mm length unless the fish remain in the river to become yearlings. Migration speed of smolts is related to river flow.

Chinook salmon spend 1 to 5 years maturing in the ocean before returning to freshwater to spawn. Survival is poorly known, but believed to be on the order of 80% for natural mortality after age 2; most mortality probably occurs early during ocean residence. Early growth and survival appears to be highly variable, with poor conditions along the west coast during El Niño.

In estimating the potential influence of EWA and other restoration actions on chinook salmon, it is useful to consider the likely loci of density dependence, and the major sources of mortality. Density dependence in salmonids occurs most often during spawning and rearing, both of which can be constrained by availability of habitat space. Density dependence in the ocean seems unlikely for the more depleted Central Valley stocks and has not been demonstrated here, although it has been seen in more abundant stocks in the Pacific Northwest. If density dependence occurs only during spawning and rearing, then increases in abundance due to actions in the rivers or the estuary should carry through to recruitment to the ocean fishery.

The relative magnitudes of the various mortality factors in the life cycle of the salmon are poorly known. Survival of eggs and alevins may be depressed by superimposition if adults are very abundant in relation to spawning habitat, and rearing habitat may limit production of juveniles. Flow and especially temperature in the rivers may influence survival of eggs and alevins. The effect of flow and temperature on fry are less well-known since they can move to escape unsuitable conditions. In particular, the importance of rearing in the Delta, and survival of salmon there compared to those that rear in the rivers, is unknown. Survival in the ocean, too, is poorly known, except that the harvest fraction exceeds 60% and has been nearly 80% in some years.

Water project operations can affect streamflow, temperature, and sediment loading, all factors that affect salmon movement and survival. In the Delta, the area of principal EWA concern in 2000–2001, water projects affect flows in the channels by reservoir releases, operation of the Delta Cross Channel gates, and pumping from the south Delta. Although the emigration timing of each run is different, juvenile chinook salmon are in the Delta and vulnerable from October through June. In most years the period of maximum abundance is from January through May.

Considerable management attention has been focused on movement of salmon smolts through the Delta. Mark-recapture experiments with coded-wire-tagged smolts and yearlings have been used extensively for analysis of survival and effects of various operations (Brandes and McLain 2001). Analyses of abundance and movement have used length criteria that vary by date to distinguish races, but these criteria are not very accurate in most years. Genetic analyses are proving useful in identifying fish, at least for the endangered winter run.

Several attempts to model the life cycle of chinook salmon have been made. The most recent has been the development of an individual-based model for the Sacramento Basin, supported by the US Fish and Wildlife Service under the CVPIA. At present that effort has stalled because of a lack of funds, but even with adequate funding some of the parameter estimates, particularly for mortality, would be fairly unconstrained. Although this model should eventually be useful for exploring the effectiveness of various actions, it will not provide a substitute for field studies.

Winter Chinook

This run historically spawned in the late spring and early summer in spring-fed streams draining Mount Lassen. Shasta and Keswick dams, constructed in the early 1940s, blocked winter chinook from their former spawning grounds but cold water released from the Shasta reservoir allowed spawning to occur in the Sacramento River from about Redding to the base of Keswick Dam.

Listing status. The winter chinook was first listed in 1989, and is now listed as endangered under the state and federal endangered species acts.

Adult age structure. Most winter chinook leave the ocean at age 2 or 3 years.

Time of spawning migration. Maturing winter chinook enter the estuary during the winter and move upstream where they may hold for a few months before spawning.

Time of spawning. Spawning generally occurs from May into August.

Spawning location. Generally restricted to the mainstem Sacramento River, although there may be some straying into Battle Creek

Juvenile emigration. Most juveniles emigrate from the upper river as smolts, with the majority moving through the Delta from January through March.

Adult abundance. The numbers of adult winter chinook have been estimated from daily counts of salmon passing fish ladders at the Red Bluff Diversion Dam. In recent years, the dam gates have been raised during most of the migration period, so the counts must be extrapolated based on the estimated fraction of the migration period sampled. Thus, the estimates are far less accurate than they were in the 1960s and 1970s. DFG, the USFWS and NMFS are evaluating other methods, such as carcass surveys, to obtain more reliable counts. In any event, the official winter chinook spawning escapement estimates are from RBDD fish ladder counts. The data demonstrate a precipitous decline in numbers from the late 1960s through the late 1980s (Figure 11A); however, the past 10 years offer some encouragement in that the cohort replacement ratio has been positive in the 1990s (Figure 11B). The cohort replacement ratio (CRR) is the number of adults returning from a cohort divided by the number of adults in the original cohort. From 1990 to 2000 the CRR has averaged 1.7 (90% confidence limits 1.2–2.3), assuming a 2.5-year generation.

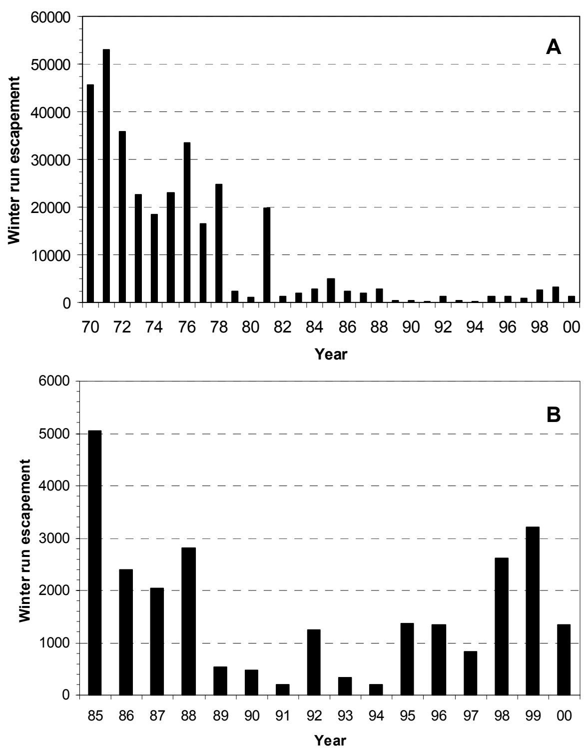


Figure 11 Winter run escapement: (A) 1970–2000; (B) 1985–2000. Source: T. Mills, CALFED.

Hatchery contribution. Since 1998 the USFWS has spawned and reared winter chinook to supplement natural production. The juveniles are reared to smolt size and released during the winter (typically late January) in the Sacramento River near Redding. Annual winter run hatchery releases between 1989 and 1999 have ranged from a low of about 1,000 to a high of 155,000, with the average of about 35,000. The number of adults captured for spawning is limited to minimize possible harm to the run's genetic integrity.

Spring Chinook

Spring chinook, which historically spawned in the upper reaches of Sacramento Valley and San Joaquin Valley tributaries, may once have been the dominant Central Valley chinook salmon run (Yoshiyama and others 2001). Dam construction has eliminated access to historical spawning habitat and the spring run has been extirpated from the San Joaquin system and greatly reduced in the Sacramento system.

Listing status. Spring chinook is listed as threatened under the state and federal endangered species acts.

Adult age structure. Adult spring run may leave the ocean at ages 2 to 5 but most leave at age 3 years.

Time of spawning migration. Adult spring chinook enter freshwater in the spring and move upstream to hold several months before spawning.

Time of spawning. Spawning occurs from September through November with the peak typically in September and October.

Location of spawning. The majority of spring run spawning is now confined to a few Sacramento River tributaries including Butte Creek, Mill Creek, and Deer Creek. A common feature of these streams is access to colder water high in the Sierra Nevada. In good water years, there may be significant spring run spawning in some smaller streams. Spring run may be present in the Yuba River. There is a putative spring run propagated by DFG's hatchery on the Feather River. This run, which now spawns in the same general area as fall run, is genetically dissimilar from spring runs in Mill, Deer, and Butte creeks and appears closer to the fall run (Figure 9). There are phenotypic differences in the runs to the Feather River with bright fish, putative spring run, arriving in the spring.

Juvenile emigration Juvenile emigration in spring chinook is complicated and is not fully understood. Spring-run juveniles may leave their natal streams as fry, smolts, or yearlings. The proportion of each life stage leaving any given stream, and the dependence of that proportion on rearing conditions, are unknown. The lack of knowledge is partly due to low abundance and partly due to similarity of spring-run to co-occurring fall-run fish. Better genetic markers are needed.

Adult abundance With their long holding period, remote spawning site, and low abundance, enumeration of adult spring chinook is difficult. The estimates for Butte Creek (Figure 12), which recently has had the largest runs, indicate that in the past four decades total run size has varied from a few hundred to several thousands of fish.

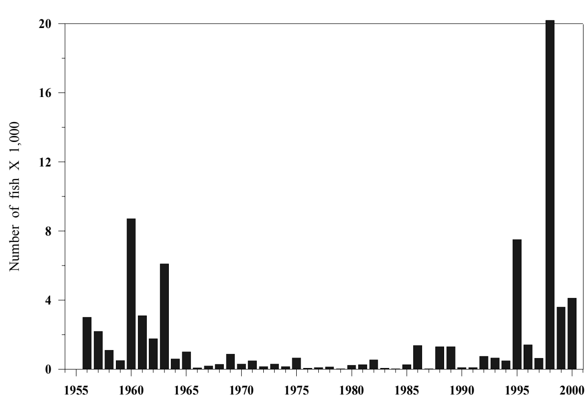


Figure 12 Annual spring-run escapement to Butte Creek

Hatchery contribution. Currently only the Feather River Hatchery propagates spring chinook and, as mentioned above, there is some question about the genetic identity of that production. The entire production, typically on the order of 5 million fish, is trucked to San Pablo Bay for release as smolts. Since 1994, a significant fraction of the released fish has been tagged (coded wire tags) and the tagged fish have fin clips. Analyses are underway to determine contributions to the ocean fishery, straying, and return to the Feather River. Black (2001) describes historical salmon hatchery production in the upper Sacramento Valley, including unsuccessful attempts at rearing spring chinook at the CNFH, and supplementing natural stocks by transporting spawners to tributaries such as Deer Creek.

Fall Chinook

The fall run is now the most abundant race in the Central Valley with numerous streams supporting significant spawning populations. The fall run also is the backbone of extensive ocean commercial and recreational fisheries and the inland recreational fishery. Much of the fall run's apparent success is due to an effective hatchery supplementation program.

Listing status. Central Valley fall chinook is a candidate species under the federal Endangered Species Act.

Adult age structure. Although fall run chinook predominantly return as 3 -year-olds, during some years there are significant numbers of age 2 and 4 spawners, with occasional five-year-old fish.

Time of spawning migration. Fall run typically enter San Francisco Bay in the early fall and proceed directly to the spawning grounds.

Time of spawning. Fall run spawn from September through December with peak spawning typically from October through mid November.

Spawning location. Most of the eastside tributaries to the Sacramento and San Joaquin rivers support runs of fall chinook, as do some westside tributaries to the Sacramento River. Fall run spawn in the lower reaches of these streams, thus were historically isolated from spring chinook. Dam construction has had less effect on this race than on spring and winter chinook. By far, the majority of fall-run chinook spawn in streams below major hatcheries on Battle Creek, the Feather River, the American River and to or lesser extent on the Mokelumne and Merced rivers.

Juvenile emigration. Fall chinook exhibit plasticity in their pattern of juvenile emigration. By the end of March, most juvenile fall chinook have left their natal streams as advanced fry and fingerlings (see for example, Williams 2001; Sommer and others 2001a). That they leave is clearly demonstrated from catches in screw traps. Their fate after leaving the streams is not as clear. They may reside in the lower stream reaches or the Delta but this has not been well documented. In most streams a significant fraction of the juveniles leave the streams as smolts in April, May, and early June. The smolts appear to move downstream and through the Delta rather rapidly and are in the downstream embayments or the coastal ocean by the end of June. Finally it appears that a small but undetermined fraction of the zero age class juveniles remain in the streams during the summer and emigrate the following fall and early winter. All winter, late fall, and spring run, and most fall run juveniles originate in the Sacramento Valley. This disparity in numbers between the Sacramento and San Joaquin basins can affect allocation of EWA assets. The problem arises in that all salmon are mixed in the Delta and it is difficult to determine their origin and race.

Adults in the San Joaquin River system. Total spawning escapement to the major San Joaquin River tributaries (Stanislaus, Tuolumne, and Merced rivers) has varied considerably over the past few decades (Figure 13), and is generally much lower than seen on the Sacramento River. Since Friant Dam was closed, there has been no salmon spawning in the mainstem San Joaquin River.

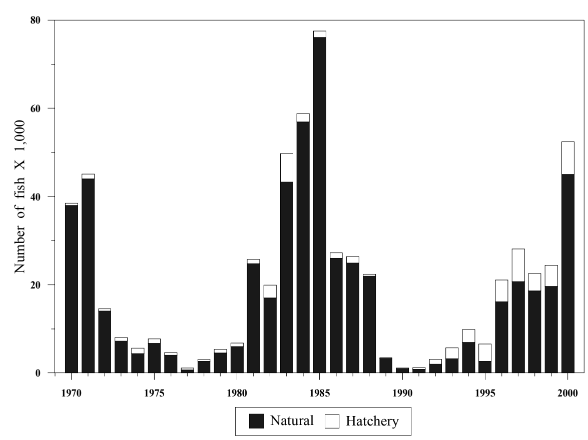


Figure 13 Annual fall-run escapement to the San Joaquin River system, natural and hatchery contribution

Adults in the Sacramento River system. Major fall runs occurring in the mainstem Sacramento and its tributaries (Battle, Mill, Deer, Clear, and Butte creeks) and the American and Feather rivers result in relatively robust fall chinook escapements (Figure 14). The management goal is to have an escapement between 120,000 and 180,000 fish. This goal has generally been met, albeit mostly because of hatchery production. In some streams many of the naturally-spawning fish were reared in a hatchery, and the degree of dilution of the genetic makeup of the current “natural” stock by hatchery fish is unknown.

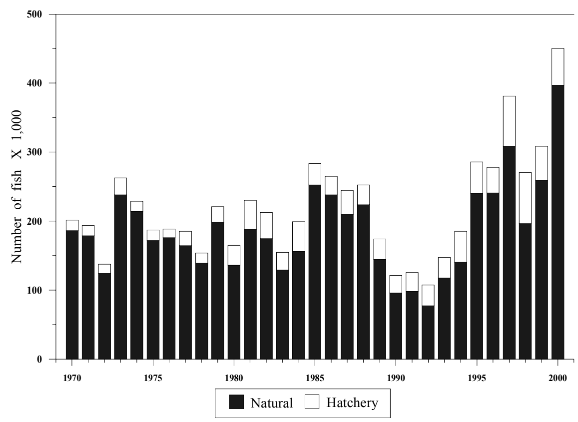


Figure 14 Annual fall-run escapement to Sacramento River and major tributaries, natural and hatchery contribution

Hatchery contribution. There are five Central Valley hatcheries releasing approximately 25,000,000 fall chinook smolts annually—the Coleman National Fish Hatchery, the Feather River Hatchery, the Nimbus Hatchery, the Mokelumne River Hatchery and the Merced River Fish Facility. Production from the FRH and Nimbus is trucked to San Pablo Bay for release, as is a significant fraction of the Mokelumne River production. The remainder is released directly in the streams or used in experimental releases in streams and the Delta. An effort is underway to evaluate the effects of these hatchery releases; however in many cases, not enough of the production has been marked to provide statistically adequate sample sizes. Through efforts by CALFED and others, agencies are proposing to mark a constant fraction of all hatchery production with the goal of using tag recoveries to better understand hatchery impacts.

Late-Fall Chinook

As seen in Figure 9, late fall chinook genetically closely resemble their fall spawning kin. Although there are phenotypic differences, late fall chinook was not recognized as a separate race until the 1960s.

Listing status. Late fall chinook is a candidate species under the federal Endangered Species Act.

Adult age structure. Although information is sketchy, it appears that late-fall run has a higher proportion of older, 4- and 5-year-old fish. This conclusion comes from their generally larger size than fall chinook. It may be that these fish are less vulnerable to the ocean fishery and therefore live longer.

Time of spawning migration. As implied, late-fall chinook enter freshwater during the late fall and early winter months. Like fall chinook, they arrive on the spawning ground fully mature.

Time of spawning. Again the data are somewhat sketchy but spawning appears to peak in January and February.

Spawning location. Late fall chinook apparently spawn only in the mainstem of the Sacramento River and Battle Creek, although some straying may occur.

Juvenile emigration. Juvenile late fall chinook remain in the stream over the summer before emigrating during the fall and winter months.

Adult abundance. With the Red Bluff Diversion Dam gates up most of the year, there is no way to estimate adult abundance. Traditional mark-recapture spawner estimating methods are not effective for a fish that spawns during the winter months when stream flows and turbidity are often high. Total escapement is probably on the order of 10,000 to 20,000 adults.

Hatchery contribution. The Coleman National Fish Hatchery annually produces and releases about 1 million late-fall chinook in the upper river. Most releases are in mid-winter but some experimental releases may occur in the fall. In recent years some late fall juveniles have been used in Delta survival experiments. All late fall production is marked and tagged.

Central Valley Steelhead Rainbow Trout

The following information has been extracted from McEwan (2001).

Steelhead is the anadromous form of rainbow trout, although the species is polymorphic and progeny may exhibit a different life history than their parents, for example, moving between anadromy to residency. This plasticity may enable populations to survive an extremely variable environment, such as the when sand bars at stream mouths are not breached by high flows.

Historically steelhead populations were widely distributed from southern California coastal streams, in the Central Valley to Alaska and the Kamchatka Peninsula. There are three runs—winter, summer, and fall—named according to the time they migrate to the spawning grounds. Human activities, logging, water management, flood control, agriculture and hydropower dams have severely limited steelhead production and many populations, or Evolutionary Significant Units (ESU), from California to British Columbia have been listed and some are in danger of becoming extinct.

Much of what we know about Central Valley steelhead came from DFG studies conducted in the 1960s. In recent years most of the salmonid biologists have focused on chinook salmon. Steelhead and chinook salmon life histories are sufficiently different that findings from salmon studies cannot be directly applied to steelhead.

Listing status. The Central Valley steelhead ESU is listed as threatened under the federal Endangered Species Act. The ESU applies to all anadromous forms of rainbow trout but not landlocked forms that may have been isolated by dam construction.

Adult age structure. Unlike chinook (and other Pacific salmon) steelhead adults may spawn more than once thus the spawning run can consist of many cohorts. Typically, the spawning run consists of mostly 3- and 4-year-olds.

Time of spawning migration. All Central Valley steelhead are now apparently of the winter variety, and peak migration has been observed to be during the months of September through November.

Time of spawning. Peaks in January through March but some spawning may occur as late as May.

Spawning location. Through alteration and loss it appears that at least 80% of the original steelhead spawning habitat is no longer available. Populations now occur in the upper Sacramento River, Battle, Deer, Mill and Butte creeks, the Feather and American rivers in the Sacramento Valley and in the Mokelumne, Calaveras and Stanislaus rivers on the San Joaquin side. These populations have been detected by monitoring efforts largely directed towards other fish. It is likely that additional populations exist in streams where there are no monitoring efforts.

Juvenile emigration. The majority of juvenile Central Valley steelhead emigrates from late December through May (mid-March peak) as two-year-olds. The average size of these emigrants is 150 to 200 mm.

Adult abundance. There are no reliable estimates of the numbers of adult steelhead escaping to Central Valley streams. McEwan (2001) estimated that there may have been 1 to 2 million historically, a number which had dropped to a few tens of thousands by the 1950s. The Red Bluff Diversion Dam fish ladder counts showed an average escapement of about 11,000 from 1967 to 1976. This average had dropped to around 2,200 spawners in the 1990s. It is unlikely that the present total Central Valley run exceeds 10,000 spawners, including returns to hatcheries.

Hatchery contribution. Steelhead are reared in 4 Central Valley hatcheries (Coleman, Feather River, Nimbus and Mokelumne), with annual releases averaging about 1.2 million fingerlings and 1.5 million yearlings. Hatchery operators release production near the hatcheries and many of the released fish are caught by local anglers soon after release. All hatchery fish are marked with an adipose clip and anglers must release all non-clipped (wild) steelhead. Hatchery practices, including source of founding stock, have affected the genetic integrity of Central Valley steelhead. Allozyme analyses by NMFS (1997), demonstrated that steelhead from the Coleman and Feather River hatcheries and wild fish from Mill and Deer creeks and the Stanislaus River were genetically similar. On the other hand, wild and hatchery steelhead from the American River formed a distinct group, most closely resembling their Eel River founding stock.

Vulnerability to Delta conditions and water project operations. Other than the general timing of their abundance in the Delta, relatively little is known about how well juvenile steelhead handle Delta conditions. Conditions that help salmon should benefit steelhead which, because they are larger during migration through the Delta, may be less vulnerable to various sources of mortality in the Delta. With the hatchery marking program, samplers are now able to distinguish hatchery from wild fish. This alone will help increase our understanding of steelhead movement and survival; however, we need more studies devoted strictly to steelhead.

Delta Smelt

The following information is from DWR and USBR (1994), Wang (1986) and Moyle (1976). A conceptual model (Figure 15) provides a general idea of the delta smelt life cycle.

The delta smelt, *Hypomesus transpacificus*, is a small euryhaline fish found only in the San Francisco estuary, including the Sacramento–San Joaquin Delta. Delta smelt generally have a one-year life cycle, with a small percentage of the population living a second year. Fecundity is low, with the average female having fewer than 2000 eggs.

Until 1961, delta smelt was considered the same species as the widely distributed pond smelt, *Hypomesus olidus*. In 1993, DNA analyses confirmed that they were separate species. In 1959, DFG had planted pond smelt (now *H. nipponensis* or wakasagi) in the estuary's watershed and the progeny of these plants found their way into the Delta.

As a result of field and analytical studies conducted since the 1980s (and expanded through the 1990s), we know quite a bit about the distribution and abundance of delta smelt and their life history. The animal is well adapted to living in the constantly changing estuarine environment, with its distribution more a function of hydrologic and tidal forcing than geography. Salinity tolerance, life history, and flow limit distribution to the estuary between San Pablo Bay and Sacramento and Mossdale on the Sacramento and San Joaquin rivers respectively. Although the distribution is generally confined to these geographic areas, in any given year flows will influence the exact distribution. For example, fish are distributed further east during the drier years and west during wet years. Conversely, there is not consensus about the factors controlling delta smelt abundance.

Listing status. Delta smelt is listed as threatened pursuant to the state and federal endangered species acts.

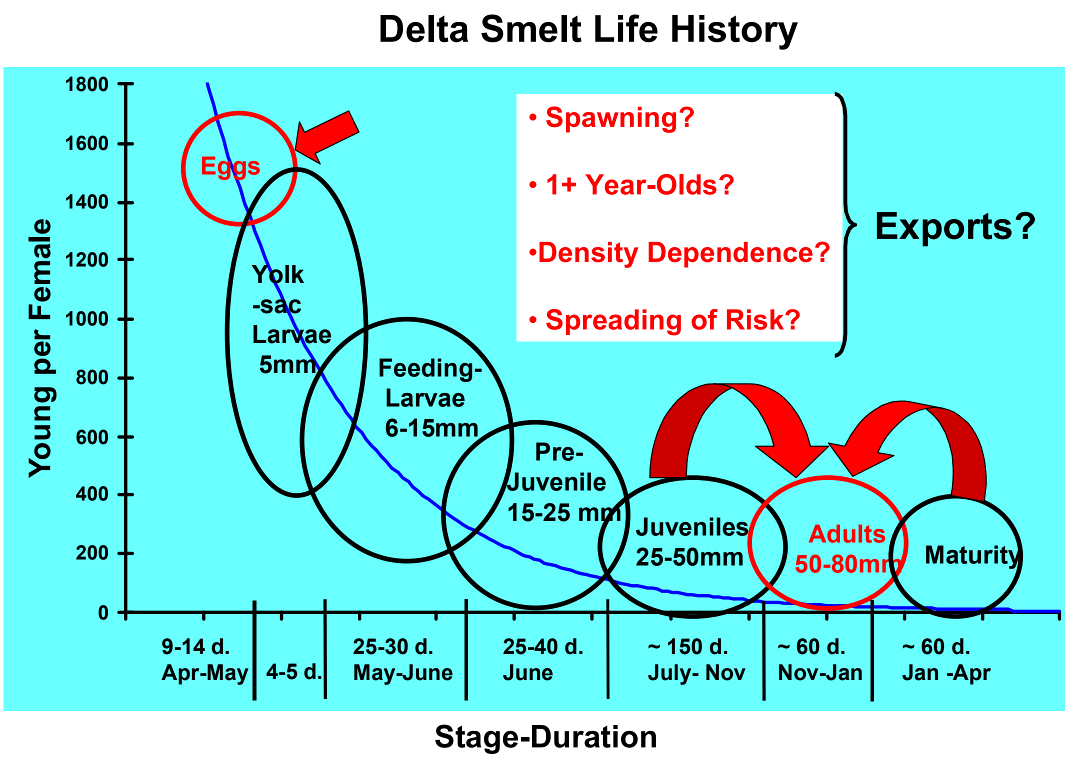


Figure 15 Delta smelt life history conceptual model. Source: William Bennett, personal communication, see "Notes."

Adult age structure. Length-frequency data indicate that about 95% of the adult population to be 1-year-old fish. These results were obtained by analyzing length frequency diagrams

Time of spawning migration. Adult delta smelt may begin moving upstream by as early as December and continue through May.

Time of spawning. Spawning may occur from December through June, depending on hydrology and temperature, although in most years peak spawning occurs from early April through mid-May.

Spawning location. Spawning locations are widespread and variable, depending at least in part on hydrology. Important spawning areas are: Cache Slough, Montezuma Slough, in the vicinity of Venice Island and the Sacramento River near Isleton. In the wetter years, spawning may occur in the Napa River. These locations have been determined by the capture of ripe adults and free-swimming larvae. Few of the adhesive eggs or very early larvae have been observed.

Juvenile downstream movement. Although it is likely that juvenile delta smelt exert some influence on their downstream movement (perhaps by rheotactic or phototactic responses), downstream movement is more of a passive process than for other fish being considered in this report. The primary rearing area is typically in the western Delta and Suisun Bay and presumably population viability is enhanced when the maximum number of juveniles reach this area. In most cases, delta smelt are below the confluence of the Sacramento and San Joaquin rivers by the end of June.

Adult abundance. There are no reliable estimates of the numbers of adult delta smelt, but several indices allow relative changes in abundance to be tracked. One of these indices, the IEP's fall midwater trawl (Figure 16), captures pre-spawning adults, thus providing an indication of annual adult abundance. (This is the index used to determine, at least in part, if delta smelt have recovered sufficiently to be delisted.) The data indicate that in the 1960s and 1970s, delta smelt abundance was somewhat variable, but consistently higher than in the 1980s. In 1990s, abundance has increased, but generally not to levels seen in the 1960s and 1970s.

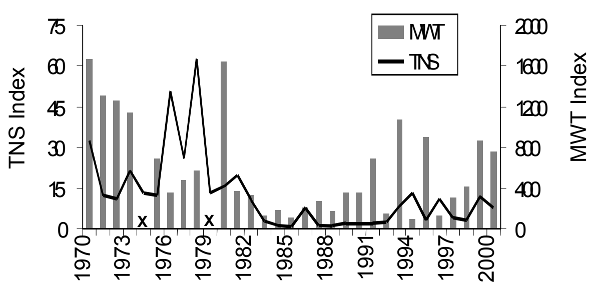


Figure 16 Delta smelt abundance indices for the townet survey (TNS) and fall midwater trawl survey (MWT) for the past 30 years. "X" indicates no sampling done in that year.

Hatchery supplementation. There is no hatchery supplement for delta smelt. However, since the early 1990s, efforts have been underway to determine if the animal can be cultured. (See, for example, Lindberg and others 2000.) These culture studies have had the dual goal of learning more about delta smelt biology and providing test fish for researchers. In recent years, the studies have achieved both goals and an early life stage roadblock (around 40 days post-hatch) has been overcome.

Vulnerability to Delta conditions and water project operations. Since delta smelt spend essentially their entire life cycle in the estuary, they are vulnerable to water project operations for a relatively long period. They are especially vulnerable during their migration to spawning grounds and during the movement of larvae and juveniles from the spawning areas to Suisun Bay and away from the reach of the Delta pumps. Maturing adults and juveniles are entrained in water project and agricultural diversions and pumping and reservoir releases affect changes in Delta hydrology. The period of maximum vulnerability is from January through May, or about the same period of concern for salmonids.

Splittail

The following information is from Sommer and others (1997) and Brown (2001). A splittail conceptual life cycle is shown in Figure 17.

Splittail is the only remaining species in the genus *Pogonichthys* (family Cyprinidae), since the other species, the Clear Lake splittail, is now extinct. The splittail is endemic to Central Valley sloughs and rivers and the San

Francisco Estuary and Sacramento–San Joaquin Delta. The species was historically distributed from above Redding on the Sacramento River to the Tulare Lake Basin in the San Joaquin Valley. Although there is some indication that the present distribution is somewhat curtailed, the animal is widely caught in the watershed below dams and estuary, especially in wetter years. There is a limited splittail fishery, with the fish used for human consumption and for striped bass bait. Young and Cech (1996) have shown splittail to tolerate a wide range of salinity and dissolved oxygen concentrations, including salinities approaching 30 ppt and dissolved oxygen concentrations of less than 1 mg/L. This tolerance allows the animal to exploit a wide range of niches in their highly variable environment.

Listing status. The splittail is listed as threatened under the federal Endangered Species Act. As the result of a lawsuit, the court is reviewing the listing and a decision is expected this year.

Adult age structure. The splittail is a relatively long-lived multiple spawner with some individuals reaching 8 to 9 years of age. More typically, older individuals are mostly female and 5 to 6 years of age.

Time of spawning migration. The adults generally move up from their Delta rearing habitat to the spawning areas from January through March.

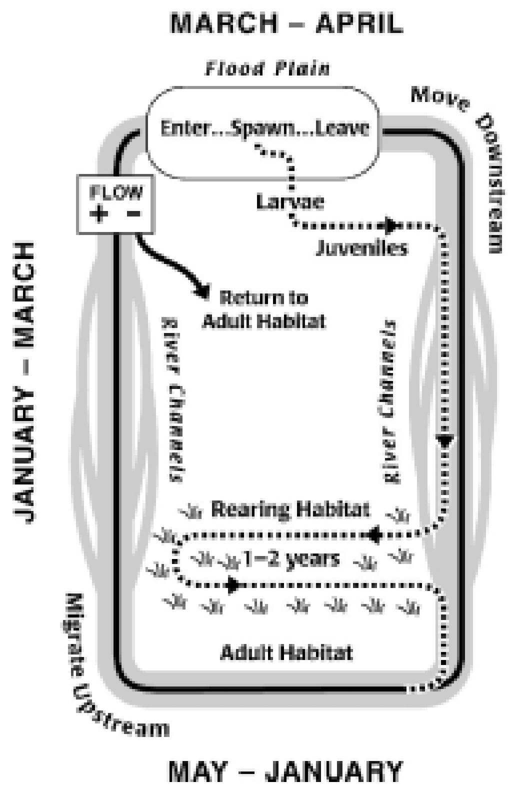


Figure 17 Splittail life history model

Time of spawning. The majority of the spawning occurs in March and April, although some spawning may happen before and after that period.

Spawning location. Splittail spawn on flooded vegetation and spawning locations vary depending on hydrology. On the Sacramento side, the Yolo and Sutter bypasses are major spawning areas when the bypasses flood. The Sutter Bypass may be more important in that it floods at lower flows. In the San Joaquin basin, juveniles have been observed in the Tuolumne River. The Cosumnes River, an undammed stream entering the east Delta, appears to provide valuable spawning and rearing habitat in all but the driest years. Although year class success is correlated with flow, there does appear to be some successful spawning in all years.

Adult abundance. There are no estimates of the numbers of adult splittail, nor are there surveys with the sole purpose of estimating or indexing splittail abundance. We have a series of indices from sampling programs originally designed to estimate the abundance of other species. In most instances, the gear used is not appropriate for a fast swimming fish that tends to feed towards the bottom of the water column. However, in spite of the limitations, most of the seven sampling programs provide the same general abundance patterns for mostly young-of-the-year fish. One of these indices, from the IEP's fall midwater trawl, is plotted in Figure 18. There has been considerable interannual variation in abundance, with the high abundance indices occurring in the years with wetter hydrologies. All the indices showed relatively low abundance during the late 1980s and early 1990s during a prolonged drought.

Hatchery contribution. There is no splittail hatchery production.

Vulnerability to Delta conditions and water project operations. Juvenile splittail are entrained in the SWP and CVP Delta diversions. Since year class strength is closely tied to flow, project operations can affect abundance. Levee construction and maintenance can affect spawning and rearing habitat. The effects of project operation on population viability is not known.

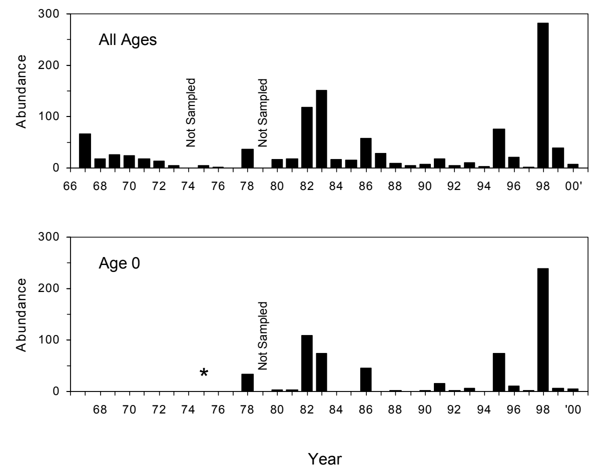


Figure 18 Splittail total annual and age-0 abundance indices from the IEP Fall Midwater Trawl Survey, 1967–2000. The length measurements for splittail were first recorded in 1975, allowing calculation of an age-0 abundance index from 1975 (asterisk) to present. The survey was not conducted in 1974 or 1979.

Green Sturgeon

In 2000–2001, protecting green sturgeon juveniles or adults did not play a direct role in allocating EWA assets, nor has this species been the focus of studies evaluating the environmental impacts of water development. Green sturgeon is, however, among the sensitive fish species using the estuary listed in CALFED's Multi-Species Conservation Strategy. The information below was extracted from Moyle and others (1992) and a June 2001 petition to list the green sturgeon submitted by three conservation organizations: Environmental Protection Information Center, Center for Biological Diversity, and Waterkeepers Northern California.

Green sturgeon is one of the few sturgeon species to spend much of its time in the marine environment. Its anadromous life cycle includes freshwater spawning and some rearing, with most growth occurring in the ocean. The animals are quite migratory: adults marked in San Francisco Bay have been recaptured in estuaries along the coast from Santa Cruz, California, to Grays Harbor, Washington. On the other hand, no animal marked in the Northwest has been recaptured in California.

Although green sturgeon are found on both sides of the Pacific Ocean, recent genetic information indicates that there are two distinct species. On the North American side, green sturgeon have been collected from southern California to Alaska. In spite of this wide range, it appears that green sturgeon use only a few river systems along the coast for spawning and early rearing - namely, the Rogue River in Oregon and the Klamath–Trinity and Sacramento River systems in California. Green sturgeon do not appear to use the San Joaquin system for spawning.

Listing status. The June 2001 petition requested NMFS to list green sturgeon as either threatened or endangered pursuant to the federal Endangered Species Act, and concurrently identify critical habitat.

Adult age structure. Since green sturgeon reach sexual maturity at ages from 15 to 20 years, with a maximum life span of several decades, the adult population will contain several cohorts. Population age structure is further complicated by the fact that the oldest fish are virtually all females and they spawn infrequently, perhaps every 3 to 5 years.

Time of spawning migration. Mature sturgeon apparently ascend to their riverine spawning grounds in the spring and early summer.

Time of spawning. Spawning appears to occur from March through July, with the peak from mid-April through mid-June. Relatively few larvae are captured to verify these estimates.

Spawning location. Most green sturgeon spawning apparently occurs in upper mainstem Sacramento River, although there is some evidence that the Feather River may support some spawning.

Juvenile emigration. Juvenile green sturgeon may spend 1 to 4 years in freshwater with 2 years most common. Outmigration may be tied to flows, but this has not been confirmed.

Adult abundance. Using a ratio with the more common white sturgeon, DFG estimated an average of 873 adults during the period 1954 through 1998.

Hatchery supplementation. There is no green sturgeon hatchery production.

Vulnerability to Delta conditions and water project operations. A few juvenile green sturgeon are salvaged at the CVP and SWP intakes. In 1993, seining Clifton Court Forebay captured 28 large (mean length 657 mm, range 416–1632 mm) green sturgeon (Brown 1993).

Conceptual Models for EWA Actions

The Environmental Water Account is one of the CALFED actions aimed at restoration of fish populations. Here we present a conceptual model of how overall restoration may work, and how EWA actions may fit into the overall program.

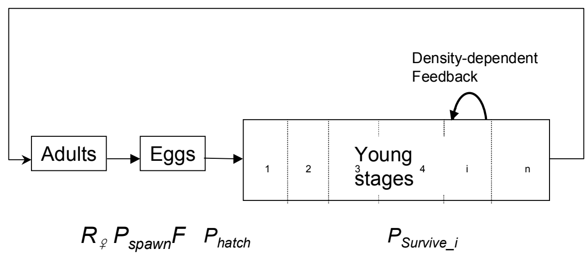
The goal of CALFED restoration actions relevant to EWA is to increase populations of fish species of interest. In general, to increase populations requires that the average cohort replacement rate (*CRR*) increase as much as possible over 1. A simple definition of the *CRR* is the ratio of the number of adults in a year class divided by the number of adults in the spawning population that produced them. A *CRR* of 1 means that the population neither increases nor decreases in the long run. More specifically, the population changes according to the following equation:

$$N_G = N_0 \, CRR^G \tag{1}$$

where N_0 is the initial number, N_G the number of fish in the population after G generations, and *CRR* the average cohort replacement rate. Note that the rate of change of the population will also increase if the generation time G is shortened, but this is probably neither feasible nor desirable for wild fish populations.

The population abundance after a single generation is equal to the number of spawning females, times the probability of spawning, times the total fecundity of the females that spawn, times the probability of surviving for each subsequent event (for example, passage by a diversion) or time period (day or other time, or life stage) until the age at which the fish spawn (Figure 19). Cohort replacement rate in this simplified case is N_1/N_0. Neglecting density dependence (see below), none of the factors in Figure 19 is related to population size, in which case increasing fecundity or any of the probabilities by a given proportion will increase cohort size by that proportion.

Each of the factors in Figure 19 may be controllable by humans to some degree. For example, a controllable factor would be increasing the spawning success of adults through the use of hatcheries, while an uncontrollable factor would be variation in adult survival due to climate conditions. The EWA actions in general have been designed to increase survival of young fish.



$$N_1 / N_0 = CRR = R_{♀} P_{spawn} F P_{hatch} P_1 P_2 P_3 \ldots P_n$$

Figure 19 Simplified schematic diagram of factors affecting production of a cohort of fish, and an equation showing the relationship of the number in one generation N_1 to that in the previous generation N_0. $R_{♀}$ is the proportion of adults that are female, P_{spawn} the probability of spawning, F the mean fecundity, and P_{hatch} the probability of hatching. The remaining P values are probabilities of survival over successive life history stages. For the purposes of EWA, one of the *P* values is probability that a fish will not be killed through entrainment at the export facilities.

Changing any of the factors in Figure 19 should change the *CRR* proportionally, provided there is no density dependence (see below). Suppose, for example, that the cumulative probability of dying because of factor *i* is 10%, that is, the associated probability of survival is 90%. Then if that factor were eliminated entirely, the *CRR* would increase by a factor of 1.11 (in other words, 1/0.9). Suppose instead that only a portion of that factor could be eliminated, say half. In that case the CRR would increase by a factor of 1.05 (here, 1/0.95). Thus, to influence the CRR by manipulating a particular factor in the life cycle, it is best to select a factor that has a large influence (that is, for which the *P* value is small) and that is highly controllable.

A full evaluation of the effects of a restoration action would include a determination of the change in *CRR* (and therefore time trend of the population) attributable to the action. This is at least impracticable, and may be impossible, in a complex system because of the multitude of unobserved factors that vary substantially from year to year. The standard of evidence for a favorable effect of reducing a mortality factor should therefore include answers to the following questions.

- What is the magnitude of this mortality factor (or *P* value in Figure 19)?
- What are the magnitudes of other mortality factors?
- What degree of controllability can be achieved for this factor?
- Given all of the mortality factors together, what is the expected change in population trajectory if the selected factor is changed?

An additional consideration is the cost effectiveness of the action. That is, what is the ratio of increase in *CRR* to the cost of the action? This calculation is useful for comparing among alternative uses of resources (for example, money, water), for justifying the actions taken, and for making actions efficient.

In the case of the Sacramento–San Joaquin Delta, an obvious mortality factor is the export pumps. They move a lot of water and entrain a lot of fish. For example, between 1990 and 1995, CVP and SWP operators salvaged an estimated annual average of 50,0000 juvenile chinook salmon at their fish protection facilities. Furthermore, pumping is controllable, although the cost of reducing pumping is very high. Thus, the use of limits on export pumping has at least one and possibly both of the attributes of a useful manipulation for restoring fish. The main problem with this analysis is that the losses of fish to the pumps must be placed in the population context (Figure 19) to assess the magnitude of this particular survival probability. We attempt this in the next section.

An ideal species-specific management or restoration action would be applied as specifically as possible in time and space. The timing of the action depends on the ability of monitoring programs to determine when the population will be most susceptible to the action, or alternatively, when it is most susceptible to the mortality factor that the action is designed to reduce. Export pumping in the Delta is controlled on a daily basis, and the most immediate information about the magnitude of the mortality factor is the number of fish arriving at the pumps. Therefore controlling exports on a daily basis has at least the potential for maximizing efficiency of this action compared to an action applied on a seasonal basis (for example, export:inflow ratios, seasonal flow, or salinity standards).

Density Dependence

The effect of density dependence in the life cycle is to establish a feedback between population or cohort abundance and fecundity or survival (Figure 19). That is, a factor is density dependent if an increase in population causes the CRR to decrease. A strongly density-dependent factor will greatly constrain the effectiveness of actions taken in the life cycle before that factor has its effect. For example, density dependence in striped bass between their first summer and recruitment at age 3 years may greatly reduce the strong effect of freshwater flow on early survival (Kimmerer and others 2000, 2001). If this is true, increasing freshwater flow is not an effective way to produce more striped bass.

Several points are relevant with regard to density dependence (DD) in analyzing effects of restoration actions on fish populations.

- Generally habitat limitation implies a DD effect.
- For salmonids, DD effects are most commonly observed in saturation of spawning habitat or rearing habitat; DD effects in the ocean have been claimed but not for Central Valley fish.
- For species that are clearly not abundant enough to saturate their environment, DD effects are probably uncommon (for example, winter-run salmon probably do not saturate their spawning habitat).
- Delta smelt are a different story, and there may be density dependent effects between summer and fall (Bennett, personal communication, see “Notes”).

In the absence of hard information, assuming no density dependence is usually conservative with regard to the fish, but not with regard to the resources needed for restoring the population. However, it may be critically important to detect density dependence if it occurs, because of the possibility that it could eliminate positive effects on the fish population of costly actions.

Population Consequences

The populations of fish affected by EWA actions are expected to change through reduction in mortality at the pumps, resulting in higher survival and an increasing population relative to its size in the absence of EWA actions. We assume density dependence is negligible, but discuss its likely importance for each species below.

The population changes according to equation (1). In a real fish population the various factors making up the CRR (Figure 19) vary widely resulting in large variability in *CRR*. Thus, the actual trajectory of population change cannot be predicted. However, without an effect of density dependence, the difference in trajectories between the base case and the case where the action is taken can be calculated using the above equation. Below we estimate how the *CRR* would change with and without the EWA actions using a range of possible values to see how these translate into rates of population change.

The EWA actions in 2001 were all reductions in export flow. The purpose of reducing export flow is to reduce "take," which is the estimate of the number of fish killed at and in the immediate vicinity of the pumping plants. The calculations of take involve a number of uncertain factors, including mortality due to predation in the waterways leading to the pumps, screen efficiency, handling mortality, and mortality on release of salvaged fish into the estuary. We neglect these issues for now.

The magnitude of the actual effect of the action cannot be determined from the observed population trend, since there is no control (nothing to compare the trend to), and it must be inferred from other evidence. This makes assessing any management action difficult, and reinforces the need for careful research and monitoring to provide ancillary information about individual survival factors and how they are affected by management actions.

The Management Agencies have established guidelines for EWA actions based on various assumptions about how past conditions have allowed for higher fish abundance. Among the guidelines used are "yellow light" and "red light" levels of take at the export facilities. When these levels are reached certain actions are taken including export reductions using EWA water. However, these levels remain fixed, with the paradoxical consequence that when the fish are abundant (and therefore many are taken at the export facilities) these levels are more likely to be exceeded. Increases in population size, the goal of restoration, will result in more rather than fewer perceived problems with export pumping.

Chinook Salmon

For chinook salmon much of the concern has been about survival of smolts migrating through the Delta, and how survival is affected by export pumping. The main focus for EWA has been on winter-run chinook, although other races are involved, and on reducing export flow rate, thereby reducing this mortality factor. The calculations of take at the pumps, and the proportion of the cohort that is taken, vary depending on who is doing the calculating. The proportion lost to export pumping can be determined as the ratio of the estimated take at the pumps to the estimated number of smolts arriving in the Delta. Alternatively, one can use empirical relationships between estimated smolt survival from mark-recapture experiments and export flow.

We consider here only the direct reduction in mortality, not any more subtle, second-order effects on the fish that are not taken by the pumps because of the action. These could arise because of changes in flow patterns in the Delta (see "Delta Hydrodynamics" section).

Mortality of migrating salmon due to take at the export pumps is an event-based mortality, to which the salmon are presumably exposed once during their migration. This is in contrast to a continuous mortality such as predation mortality, or export mortality to delta smelt, both of which presumably act over time. The survival factor (Figure 19) associated with take at the export pumps is:

$$P_i = 1 - T/N = 1 - Q_E\, A/N \qquad (2)$$

where T is the total take at the pumps, N is the number of smolts in the cohort that move through the Delta, Q_E is export flow during the migration period, and A is mean abundance of fish per unit volume entrained during that period.

Reducing export pumping during the peak time of migration is expected to reduce the take in proportion to the number of fish per unit volume. Assuming that most of the fish are exposed to export pumping during the peak period when exports are curtailed, the "revised" survival factor is:

$$P'_i = 1 - T'/N = 1 - Q'_E\, A/N \qquad (3)$$

where the prime symbols indicate a revised value for survival probability, flow, and take.

The ratio A/N is a function of position of the Delta Cross Channel gates, flow, temperature, predator abundance, and probably other factors, but is unlikely to be related strongly to export flow. Thus the increase in survival can be estimated from the above equations using the change in flow:

$$P'_i = 1 - (1 - P_i)\, Q'_E/Q_E \qquad (4)$$

Figure 20 shows the increase in a salmon population after 10 generations (30 to 40 years) resulting from various assumed values for take as a percentage of the cohort and percentage reduction in export flow. The target take used to calculate the Red Light limit for winter-run salmon was 1% of the cohort (2% of the estimate based on size, which was assumed to be about half winter-run salmon). In

2001 this was exceeded by a factor of 2.7, so under the assumptions used to calculate production and survival of young winter-run salmon, approximately 2.7% of the actual winter-run population was taken. The reduction in export flows during the winter-run migration season was approximately 8%, assuming that the migration season lasted from January 17 through April 16, that the risk of entrainment was constant during that period, and that without EWA the flows would have been as stated in the action descriptions (assumed 10,000 cfs base flow for Action 5). Using the calculations of Figure 19, the increase in survival resulting from these actions would have given about a 2% increase in population size after 10 generations. Thus, the gains to be expected from the EWA actions in the Delta appear to be small.

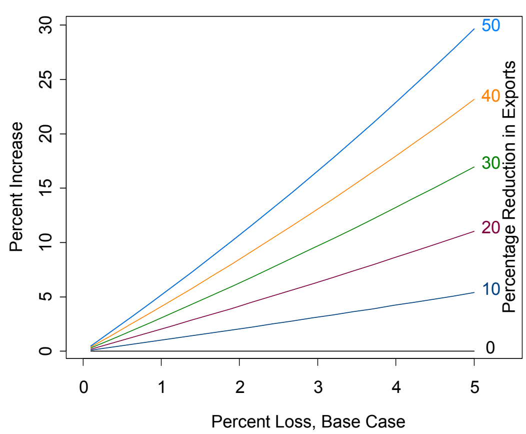


Figure 20 Percentage increase in a hypothetical salmon population after 10 generations, relative to the base case. The *x* variable is the assumed take at the export pumps as a percentage of each migrating cohort, and the numbers on the right are the percentage reduction in exports during the migration period.

The effect of the reduction in export flow on salmon fry rearing in the Delta has received little attention. At present, the contribution of these fry to the adult salmon populations is unknown. In contrast to the smolts, exposure of fry to export pumping is continuous during their residence in the Delta, which can last up to 4 months in late winter and spring. For these fish a calculation similar to that used for delta smelt is more appropriate (see below). However, salmon fry rear in shallow water that may not be very vulnerable to movement toward the pumps. In any case, without some information on the contribution of these fish to the adult populations, any such calculation would be even more speculative than those presented here.

Density dependence between the time of passage through the Delta and recruitment to the adult population in the ocean is unlikely. This has been the subject of some controversy among Pacific salmon biologists (Nickelson 1986; Emlen and others 1990). However, for the rarer races density-dependent effects during estuarine and ocean life seem unlikely.

Steelhead

Information is insufficient to calculate take of steelhead or to estimate its consequences for the population. It is probably safe to assume that consequences for migrating steelhead will be similar to those for migrating salmon, but at this point we cannot verify that assumption.

Delta Smelt

In contrast to migrating salmon smolts, delta smelt are resident in the Delta for some period of time and are exposed to the effects of export pumps continuously during that time. The exposure of delta smelt is related to their spatial distribution within the Delta and the proportion of the population that is in the Delta compared with other parts of the estuary. The biggest problems with estimating the proportional losses of delta smelt are that abundance is not known (Herbold 1996), and that the pre-screen losses and screen efficiency as a function of size are unknown. We assume that delta smelt are not successfully salvaged.

Adult delta smelt move up into the Delta to spawn in late winter to early spring. Spawning locations are unknown, and spawning must be inferred from the appearance of larvae from March through May in the 20-mm survey (Rockriver, personal communication, see “Notes”). Both adults and larvae are probably vulnerable to export pumps, but larvae are not counted in salvage. Juvenile delta smelt tend to be more abundant in Suisun Bay rather than the Delta, and should not be very vulnerable to export effects. However, salvage records indicate high numbers of delta smelt are collected from May through July of some years. Therefore, for the purposes of estimating effects of EWA actions, we assume the following:

1. Delta smelt are distributed about half in and half out of the Delta from January through June, and entirely out of it the rest of the year (the exact period doesn’t matter, but the fraction in the Delta does).
2. When in the Delta, delta smelt are distributed randomly.
3. Delta smelt of all life stages go with the flow.
4. The flow in the Delta is tidal and dispersive, and net flows are ignored.
5. Delta smelt are not successfully salvaged.
6. EWA flow reductions are applied evenly across the entire period of vulnerability.

Under assumptions 2 through 4, we can estimate the daily proportion of the delta smelt population entrained by the export pumps as the ratio of export pumping rate to volume of the Delta. This simple ratio includes no information about actual delta smelt abundance or distribution. However, if delta smelt are distributed randomly in a dispersive environment, the probability that a given smelt will be in the volume taken in by the pumps during a given day is simply represented by the ratio of that volume to the total volume of habitat. This calculation is no doubt wrong, since delta smelt (like other fish) are overdispersed and probably select habitat to some degree. However, until a better estimate is made, this will do.

Based on the above assumptions, the daily loss of delta smelt can be accumulated as the product of daily survival for the 7-month period. The volume of the Delta is about 1.23 km^3, so daily export flows are on the order of 2% of the volume of the Delta per day. For the period 1991–2000, the expected survival over the 6-month period of vulnerability without other sources of mortality would have been 40% (median; range was 24% to 51%). Thus, under the above assumptions the loss of delta smelt to export pumping during this period is large.

We calculated a 24% reduction in export flows for the EWA actions during an approximately 1-month period between January and February 2001. By inserting the revised flows into the calculation, we can estimate the improvement in abundance that might result from curtailing exports. This evaluates to about a 4% higher survival each year. Over 10 generations (nominally 10 years) this would amount to approximately a 50% increase in abundance if there were no density dependence (but see below).

This calculation is very crude, and the results should be viewed skeptically because of the assumptions needed to make the calculation. Nevertheless, the main point is that for a small fish species that spends much of its time in the Delta, vulnerability is likely to be high and the effect of reductions in exports more significant than for migrating salmon from the Sacramento River. It also highlights the need for some serious research and modeling on the influence of pumping on delta smelt.

In contrast to salmon, though, density-dependent effects may be important for delta smelt (Bennett, personal communication, see “Notes”). Strong density dependence may limit increases in population due to reducing export effects, in which case export reductions would be ineffective at increasing the population. More research is needed to determine the importance of density dependence to delta smelt population dynamics.

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